Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix EBS

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Engineered Alternatives Cost/Benefit Study

DOE/WIPP DOE-WIPP 95-2135

ENGINEERED ALTERNATIVES COST/BENEFIT STUDY

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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is a United States Department of Energy (DOE) project designed to demonstrate the safe disposal of Transuranic (TRU) waste in deep, geologic, bedded salt. The WIPP site is located in southeastern New Mexico. By law (U.S. Congress, 1992) the WIPP site has been withdrawn from public use and has been set aside for use in the safe disposal of TRU waste. Also by law, disposal of TRU waste must comply with rules and regulations promulgated by the U.S. Environmental Protection Agency (EPA). The disposal system design consists of multiple barriers, both natural and man-made, located in a geologic salt deposit, 2,150 feet (655.3 meters) below ground. These barriers were selected because of their ability to permanently isolate the waste from the accessible environment as required to comply with subparts B and C of Title 40 Code of Federal Regulations Part 191 (40 CFR 191). As a part of the assurance requirements, 40 CFR §191.14 requires that barriers of different types shall be used to isolate the waste. The WIPP design uses both a geologic (natural) and engineered barriers for waste isolation as specified by these regulations. However, to provide additional confidence in containment prediction calculations used to demonstrate compliance with the containment requirements, Engineered Alternatives (EA) could be used as additional assurance measures beyond those used to meet the containment requirements. This report uses the term EA to represent engineered barriers that are technically feasible processes, technologies, methods, repository designs, or waste from modifications which make a significant positive impact on the disposal system in terms of reducing uncertainty in performance calculations or improving long-term performance. These EAs, if used, function as barriers to the release of radioactive material.

The DOE has initiated a cost/benefit study to evaluate EAs for potential use as assurance measures. The purpose of this report is to provide the DOE with cost and benefit information for use in the selection or rejection of EAs, specifically should it be determined that additional barriers are needed for assurance purposes. This study includes a qualitative assessment of estimated cost, potential risks, benefits, and relative repository performance impacts from the implementation of EAs, and where appropriate, the impact on the entire waste management complex (as a system) was considered. This report is entitled, the Engineered Alternatives Cost/Benefit Study (EACBS).

The EACBS evaluated EAs using the following assumptions and guidance.

- The present baseline design of the disposal system and its predicted performance meet the containment requirements of 40 CFR 191 without additional EAs. The baseline does not include waste processing above that required by the WIPP Waste Acceptance Criteria (WAC) and does not include backfill as an option.

- The information presented in this report is to be used to select or reject EAs for assurance purposes only and not for demonstrating compliance with the containment requirements.

- The results of the EACBS analysis are qualitative. However, both qualitative and quantitative methods are used to generate the output information.

- The output of the EACBS compares the results of the EA analysis with the baseline and not to each other. Numeric ranking of EAs is not provided.

- The EA analysis uses a multi-factor approach that evaluates the cost; the risk, both incidental and accidental; and the benefit and schedule impacts that could be expected from the implementation of each individual EA. The factors are not ranked or weighted.

- TRU waste destined for WIPP can be grouped into three basic waste forms, sludges, solid organics, and solid inorganic materials.

- All waste shipped to WIPP will meet the WAC. WAC requirements reflect any necessary waste treatment or processing restrictions.

The DOE has previously evaluated EAs. For example, the Engineered Alternatives Task Force (EATF) Final Report (DOE 1991a) contained analyses of EAs for use in meeting 40 CFR 191 containment requirements. The EATF focused the analysis on an EA's ability to reduce gas generation and its impact on human intrusion scenarios. The EACBS study differs from the EATF in that the EACBS analysis generates information to be used for meeting assurance requirements rather than to address compliance with containment requirements through their inclusion in the compliance baseline. The EACBS analysis also includes information on system wide cost, risks, and public confidence.

The approach used in the EACBS was to screen potential EAs compiled from previous studies, proposed regulations, and input elicited from stakeholders. The screening process used a working group composed of technical professionals from various fields to compare the proposed EAs to an EA definition and then to determine if those EAs that meet the definition also meet regulatory and technological feasibility criteria. The output of the screening process is a list of EAs that did not meet the definition and/or screening criteria along with the justification for their rejection, and a list of EAs retained for further consideration. This list of retained EAs was then optimized to determine which EAs would be further analyzed using a multi-factor approach.

The screening processes evaluated 111 proposed EAs and screened them to a field of 54. The 54 EAs retained were further screened by the DOE using feasibility and effectiveness criteria to provide the final set of 18 EAs used by the EACBS. The 18 EAs agreed upon by the DOE for the EACBS evaluation consisted of nine basic alternatives and nine variations. The variations originated in the screening process and are noted with a letter following the original ID number. The 18 final EAs along with a brief description of each EA are listed below. Complete details of the screening process can be found in Section 2.3.1 of this report.

Analyzed Engineered Alternatives

<u>Baseline</u>

For EA comparison, the baseline is considered to be the current WIPP disposal system design. For each EA and the baseline waste meeting the WAC is emplaced in rooms that are 13 feet (3.96 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long and access drifts in waste stacks of seven-pack drums (three high) and Standard Waste Boxes (three high). No backfill is included in the baseline.

#1—Supercompact Organics and Inorganics

Solid organic and inorganic wastes are sorted to remove items that cannot be compacted. Sorted waste is pre-compacted in 35-gallon (132.6 liters) drums and then supercompacted. Usually, the contents of four supercompacted drums are placed in a 55-gallon (208-liter) drum. Sludges are not processed.

#6—Shred and Compact Organics and Inorganics

Solid organics and inorganics are shredded and compacted in 55-gallon (208-liter) drums using a mechanical shredder and a low pressure compactor. Sludges are not processed.

#10—Plasma Processing of All Wastes

All wastes are processed through a mechanical shredder and the input waste stream is controlled to ensure a suitable metal to non-metal ratio. The waste is processed through a Plasma Arc Centrifugal Treatment System and placed into 55-gallon (208-liter) drums.

#33—Sand Plus Clay Backfill

A mixture of medium grained sand and granulated clay is used as backfill. The mixture is placed around the waste stack and between the drums filling the void space between drums and unmined host salt in waste emplacement panels. A 50 percent void space is assumed.

#35a—Salt Aggregate (Grout) Backfill

A salt aggregate grout mixture is used as backfill to fill the void spaces between drums and unmined host salt in waste emplacement panels. This backfill consists of a cementitious-based salt aggregate grout with crushed salt aggregate and is pumped around the waste stack and between the drums filling the void spaces. A 20 percent void space is assumed.

#35b—Cementitious Grout Backfill

A cementitious grout backfill consisting of ordinary Portland cement, sand and fresh water is pumped around the waste stack and between the drums filling the void space. A 20 percent void space is assumed.

#77a—Supercompact Organics and Inorganics, Salt Aggregate/Grout Backfill, Monolayer of 2000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long

Alternatives #1 and #35a are combined. The room height is lowered from 13 feet to 6 feet (3.96 meters to 1.83 meters) and only one layer of drums is emplaced in the room.

#77b—Supercompact Organics and Inorganics, Clay-Based Backfill, Monolayer of 2000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long

Alternatives #1 and #111 are combined. The room height is lowered from 13 feet to 6 feet (3.96 meters to 1.83 meters) and only one layer of drums is emplaced in the room.

#77c—Supercompact Organics and Inorganics, Sand/Clay Backfill, Monolayer of 2000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long

Alternatives #1 and #33 are combined. The room height is lowered from 13 feet to 6 feet (3.96 meters to 1.83 meters) and only one layer of drums is emplaced in the room.

#77d—Supercompact Organics and Inorganics, CaO Backfill, Monolayer of 2000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long

Alternatives #1 and #83 are combined. The room height is lowered from 13 feet to 6 feet (3.96 meters to 1.83 meters) and only one layer of drums is emplaced in the room.

#83—Salt Backfill with CaO

A backfill of commercially available granulated lime (also called quick lime which consists of CaO) and crushed salt are placed around the waste stacks and between the drums filling the void space. A 50 percent void space is assumed.

#94a—Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, No Backfill

EA 94a includes two processes to treat the TRU waste. The first is an enhanced cementation process of previously solidified and "as generated" sludge. Existing sludges are fed into a mechanical crusher/shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums.

#94b—Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Sand/Clay Backfill

Alternative #94a and #33 are combined.

#94c—Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, Cementitious Grout Backfill

Alternative #94a and #35b are combined.

#94d—Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, Salt Aggregate Grout Backfill

Alternative #94a and #35a are combined.

#94e—Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, Clay-Based Backfill

Alternative #94a and #111 are combined.

#94f—Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, CaO/Salt Backfill

Alternative #94a and #83 are combined.

#111—Clay-Based Backfill

A backfill consisting of commercially available pelletized clay is placed around the waste stack and between the drums, filling the void space. A 50 percent void space is assumed.

Table E-1 lists the 18 alternatives with reference to specifications for waste form, backfill and room dimensions. The 18 EAs were analyzed with respect to the following eight factors as described in the proposed rule 40 CFR §194.44. For analytical consistency, Factors 1 and 9 from 40 CFR §194.44 have been combined in the EACBS.

1. Effects of EAs on long-term performance of the disposal system. This factor analyzes the EA's ability to limit water and radionuclide movement to the accessible environment and the potential consequences of human initiated processes or events.

2. The increased or reduced uncertainty in compliance assessment.

3. The impact on public and worker exposure to radiation (at WIPP and off-site) both during and after the incorporation of an EA.

4. The increased ease or difficulty in future removal of the waste from the WIPP disposal system.

5. The increased or reduced risk (incidental and accidental exposure) of transporting the waste to the WIPP.

6. The increased or reduced public confidence in the performance of the disposal system.

TABLE E-1

SUMMARY OF ENGINEERED ALTERNATIVES EVALUATED BY EACBS RELATIVE TO THE BASELINE

Identifier	Alternative	Sludges	Solid Organic	Solid Inorganic	Backfill	Facility Design
0	Baseline	As received	As received	As received	None	Baseline
1	Supercompact waste	As received	Supercompacted	Supercompacted	None	Baseline
6	Shred and compact	As received	Shred and Compact	Shred and Compact	None	Baseline
10	Plasma processing of all waste	Plasma Processed	Plasma Processed	Plasma Processed	None	Baseline
33	Sand plus clay backfill	As received	As received	As received	Sand Plus Clay Backfill	Baseline
35.a	Salt aggregate grout backfill	As received	As received	As received	Salt Aggregate Grout Backfill	Baseline
35.b	Cementitious grout backfill	As received	As received	As received	Cementitious Grout Backfill	Baseline
77.a	Supercompact organics and inorganics, clay-based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Salt Aggregate Grout Backfill	6'X33'X300'
77.b	Supercompact organics and inorganics, clay-based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Clay-based backfill	6'X33'X300'
77.c	Supercompact organics and inorganics, clay-based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Sand/clay backfill	6'X33'X300'
77.d	Supercompact organics and inorganics, clay-based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Salt plus CaO Backfill	6'X33'X300'
83	Salt backfill with CaO	As received	As received	As received	Salt plus CaO Backfill	Baseline
94.a	Enhanced cement sludges, shred and cement organics and inorganics, no backfill	Enhanced Cement	Shred and add clay	Shred and add clay	No backfill	Baseline

TABLE E-1 (Concluded)

SUMMARY OF ENGINEERED ALTERNATIVES EVALUATED BY EACBS RELATIVE TO THE BASELINE

Identifier	Alternative	Sludges	Solid Organic	Solid Inorganic	Backfill	Facility Design
94.b	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Clay/sand backfill	Baseline
94.c	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Cementitious Grout	Baseline
94.d	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Salt Aggregate Grout	Baseline
94.e	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Clay	Baseline
94.f	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Salt plus CaO Backfill	Baseline
111	Clay-Based Backfill	As received	As received	As received	Clay-Based Backfill	Baseline

7. The increased or reduced total DOE waste management system cost and schedule impacts.

8. The impact on other waste disposal programs.

The following discussions outlines the analysis and results for each EA with respect to the eight factors.

Factor 1—Effects of EAs on Long-Term Performance of the Disposal System

Factor 1 deals with the impacts that an EA is predicted to have on the long-term performance (not specific to the regulatory requirements) of the disposal system. Impacts are predicted using the Design Analysis Model (DAM), which considers the coupled processes of brine inflow, creep closure, gas generation, and radionuclide migration under undisturbed conditions. The consequences of three human intrusion scenarios are also considered. The DAM was originally developed by the EATF (DOE, 1991a). The three human intrusion scenarios postulate the existence of future boreholes that inadvertently penetrate the waste rooms and panels (waste horizon). These scenarios are the same as those considered in the 1992 Performance Assessment, and are fully described in SNL/NM (1993). These three scenarios are referred to in the EACBS as E1, E2, and E1E2. This factor is evaluated by considering the impacts of each EA on the following:

- Relative changes in the cumulative 10,000-year release of radionuclides based purely on the quantity of cuttings released to the surface from each of the three human intrusion scenarios

- Relative changes in the cumulative 10,000-year release of radionuclides into the overlying Rustler Formation from each of the three human intrusion scenarios.

The impacts of each EA are expressed as changes in the parameters described above relative to the baseline, which is defined as unprocessed waste emplaced in disposal panels with no backfill.

Although both disturbed and undisturbed conditions are simulated, the greatest consequences of releases are expected to occur as a result of human intrusion. Therefore, the study places emphasis on the effects of EAs on mitigating releases from the human intrusion scenarios.

Factor 2—The Increased or Reduced Uncertainty in Compliance Assessment

Factor 2 estimates the EAs ability to treat uncertainty relative to the quantity of radioactive materials that are expected to be transported to the accessible environment as a result of human intrusion scenarios. This factor estimates the uncertainties by systematically manipulating the DAM input parameters from the Factor 1 analyses using a Monte Carlo simulation for each EA analyzed. The results of Factor 2 are then used in conjunction with those of Factor 1 to characterize the potential for an EA to provide additional assurance in the performance of the disposal system.

Treatment of uncertainty in compliance assessment can be realized by reducing both the magnitude of radioactive materials released to the accessible environment and characterizing the potential variability in that quantity. Factor 1 addresses the magnitude of reduction through a Measure of Relative Effectiveness (MRE) for cuttings removal to the surface and groundwater transport to the Culebra Dolomite via the borehole, given scenarios E1, E2, or E1E2 occur. A MRE is a unitless factor that expresses the change in the magnitude of releases with respect to the baseline disposal system design. Factor 2 addresses the ability of the EAs to treat the uncertainty about these estimates of release quantity by treating the uncertainty about predictions of quantities of radioactive material that might be released as a result of the intrusion scenarios. Therefore, increasing the confidence in the performance of the disposal system.

<u>Factor 3—The Impact on Public and Worker Exposure to Radiation Both During and After the Incorporation of an EA</u>

This factor characterizes the human-health risks (incidental and accidental exposure) associated with the implementation of an EA, including those impacts realized at the WIPP site and generator or disposal facilities that handle TRU or TRU-mixed waste. Potential impacts include radiation effects (both occupational exposures and the release of material resulting from an off-normal accident scenario), effects from the release of hazardous material, and, in the case of individuals within the facilities, ordinary industrial hazards. Impacts are considered for the following five groups of individuals at the WIPP and at the generator/disposal sites:

- Workers directly involved with handling, processing, or storing TRU waste (generally referred to as "workers")

- Other workers in the facility who are not directly involved with the TRU waste (referred to as "co-located workers")

- The co-located worker who receives the highest exposure to radiation or hazardous material from TRU waste activities

- All members of the public who live within 50 miles (80.5 kilometers) of the facility where the TRU waste is being handled, processed, or stored (generally referred to as "public")

- The member of the public located off-site who receives the highest exposure from activities associated with TRU handling, processing, or disposal (often called the Maximum Off-Site Individual or MOI).

<u>Factor 4—The Increased Ease or Difficulty in Future Removal of the Waste from the WIPP Disposal System</u>

For the purpose of this report, waste removal is defined as the activity involving recovery of the waste after repository closure. In assessing the waste removal activities, the waste inventory and physical properties for each EA determine the underground panel geometry that would in turn determine the time required for underground removal (mining of the waste). Underground waste removal considers the compressive strength and density of the waste form as well as the consolidation of the backfill expected to occur after a specified period of time (if applicable). The occupational hazards for industrial accidents include the conventional hazards due to underground mining accidents, hazardous waste exposure, and radioactive waste exposure.

Factor 5—The Increased or Reduced Risk of Transporting the Waste to the WIPP

The transportation risk factor consists of the human-health impacts due to radiation- and hazardous-material exposures that could potentially result from transporting CH- or RH-TRU waste. The risk factor is defined in terms of the radiological, chemical, and non-radiological/non-chemical impacts of either normal, incident-free transportation or transportation accidents. Not all of the EAs impact transportation; backfill only alternatives are not analyzed using this factor. The results break down the total number of shipments from each storage/generator site and present the exposures to the public and workers. Where applicable, reported transportation risks and exposures are in the same units used in Factor 3.

Factor 6—The Increased or Reduced Public Confidence in the Performance of the Disposal System

This study was conducted in two phases to identify both historic and current public concerns about WIPP's postclosure performance. During Phase 1, existing public commentary was examined to identify concerns about postclosure WIPP. These comments and concerns were further analyzed to determine the relative frequency of the concerns and the persistence of concerns over time. Data sources included:

- The WIPP FSEIS (DOE, 1990b)

- Response to Comments for Amendments to 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and TRU Radioactive Wastes (EPA, 1993)

- Public Hearings on EPA's Proposed Rule 40 CFR Part 194, Criteria for the Certification and Determination of the WIPP's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and TRU Radioactive Wastes, March 21-24, 1995 (EPA, 1995)

During Phase 2, comments were collected during a series of focus group discussions and interviews in which participants were invited to share their concerns.

The combined findings from Phase 1 and Phase 2 analyses serve as considerations for selecting engineered alternatives that would address expressed public concerns. A qualitative assessment is made using the comment categories (comments were segregated based on the general nature of the concern) and determining which EAs address the concerns within these categories.

Factor 7—The Increased or Reduced Total DOE Waste Management System Cost and Schedule Impacts

Factor 7 analyzed increased or reduced cost and schedule impacts from implementation of EAs on the total DOE waste management system. The cost consists of summarized waste processing, transportation, backfill, and emplacement handling for the selected alternatives. The analyzed costs include a comparative analysis of the incremental change in cost of the screened alternatives relative to the repository baseline. This analysis estimates the level of funding that must be appropriated, the estimated manpower for the activities, and a conceptual schedule that provides start and stop dates for each EA analyzed. Cost was analyzed by developing process flow diagrams that segment the alternative into conceptual elements. The costs for the alternatives were developed on the basis of waste quantities and required throughput rates to meet the schedule constraints.

The schedule analysis provides a measure of the time required to implement an EA relative to the baseline. The schedule includes the incremental change of implementing an alternative on the baseline.

Factor 8—The Impact on Other Waste Disposal Programs

This factor includes an assessment of the impacts that the EAs will have on other DOE waste processing and disposal programs, including programs for LLW and low-level mixed waste (LLMW). Major impacts are assessed based on the additional volumes of waste that are projected to be generated by TRU waste processing with respect to each EA.

OVERALL CONCLUSION OF THE EACBS

After a decision is made concerning the use of EAs at WIPP for additional assurance purposes, any subsequent selection of EAs will be made using total disposal system knowledge. The EACBS provides comparative information concerning cost, schedule, worker and public radiological/chemical and accidental/incidental risks, disposal system performance impacts, public perception, waste removal impacts, and other waste disposal system impacts. The process for the selection or rejection of EAs will use this and other related information to weigh the relative importance and to determine which EAs will be implemented. The information in this report should not be used as the sole bases for the selection/rejection of any individual EA.

Table E-1 summarizes the 18 EAs analyzed in the EACBS. Each alternative was evaluated using the eight factors. The analysis results were compiled in a tabular summary and converted into quantifiable performance measures. Some factors were reported with one measure, while other factors could not be adequately expressed with a single measure. Table E-2 summarizes the performance measures and units presented for each factor. Table E-3 summarizes selected output information from the analysis of each EA and the baseline with respect to the eight factors.

The product from the evaluation of each factor was integrated into a qualitative result called a performance vector, that expresses the performance of an EA with respect to the baseline. As is the case for any analysis, these results are conditional on the models, data, and assumptions used in the analysis. Models, data and assumptions used in the analysis are described in Chapter 3.0. These models, data, and assumptions are based on the best available current information, and are considered to be appropriate for the purposes of this study. Technological understanding of many topics considered in this analysis is advancing rapidly, however, and it should be noted that changes in the modeling system or the model input, such as possible changes in our understanding of the future performance of specific EAs, could lead to somewhat different results. Table E-4 summarizes the results of the EACBS analysis and provides the performance vectors for each of the selected EAs plus the baseline repository design.

The EAs can be separated into three general categories, Waste Processing, Backfill, and Combination of these alternatives. The following observations were noted from the results of this analysis.

1 **TABLE E-2**

PERFORMANCE MEASURES REPORTED

EA FACTOR	PERFORMANCE MEASURE	UNITS
1) Long term Repository Performance	Measure of relative effectiveness (MRE) of repository performance compared to the baseline.	Ratio of the mean value EA performance to the baseline
2) Uncertainty in Compliance Assessment	Measure of the relative uncertainty (MRU) of repository performance compared to the baseline.	Ratio of the range factor for EA performance to the baseline
3) Worker & Public Risk[a]	Facility worker risk	FTE-rem excess fatalities, construction and operation injuries and fatalities
	Maximum co-located worker risk	rem, excess cancer fatalities
	Co-located worker collective risk	Person-rem excess fatalities[b]
	Maximum off-site individual risk	rem, excess cancer fatalities
	Collective off-site public risk	Person-rem excess fatalities[b]
4) Impact on Waste Removal	Measure of relative difficulty of waste removal compared to the baseline.	Qualitative ranking.
5) Transportation Risk[a]	Transport crew collective radiological, nonaccident risk	Person-rem, latent cancer fatalities
	Public collective radiological, nonaccident risk	Person-rem, latent cancer fatalities
	Public maximum individual radiological, nonaccident risk	rem, latent cancer fatalities
	Public and crew collective radiological, accident risk	Person-rem, latent cancer fatalities
	Public and crew collective chemical risk	EPRG-2 ratio
	Public and crew collective non-rad, non-chemical risk	injuries, fatalities
6) Public Confidence	Listing of citizen concerns about repository performance	Not applicable
7) System Cost & Schedule[a]	Waste storage costs	1994 dollars
	Waste treatment costs	1994 dollars
	Waste transportation costs	1994 dollars
	WIPP waste placement and backfill costs	1994 dollars
	Start of WIPP operations	Date of first waste placement
	Completion of WIPP operations	Date of closure
8) Impact on Other Disposal Systems	Secondary waste volumes	Percentage change in estimated secondary waste volumes relative to the DOE low level and low level mixed waste

[a]For EAs that involve waste treatment, results are reported separately for decentralized, regionalized and centralized locations.
[b]Other units of measure are also used for non-radiological risk.

TABLE E-3

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Waste Backfill Compressive Strength (MPa)	NA	25.2	24.5	25.1	24.1	15.2	21.1	21.1	19.4	12.2	12.2	18.3	20.1	24.7	14.7	20.6	20.6	14.7	19.7	15.2
Emplacement Volume Impact (% Emplaced or Amount not Emplaced m^3)	NA	100% emplaced	100% empleced	100% empleced	100% emplaced	100% emplaced	100% emplaced	100% emplaced	41,655	41,655	41,655	41,655	100% emplaced	27,177	27,177	27,177	27,177	27,177	27,177	100% emplaced
Backfill Properties -																				
Initial Density (Kg/m^3)	NA	NA	NA	NA	NA	1,590	1,884	1,884	1,884	1,000	1,590	1,193	1,193	NA	1,590	1,884	1,884	1,000	1,193	1,000
Initial Porosity (%)						40.0	31.3	31.3	31.3	62.5	40.0	44.8	44.8		40.0	31.3	31.3	62.5	44.8	62.5
Solid Density (Kg/m^3)						2,650	2,741	2,741	2,741	2,670	2,650	2,162	2,162		2,650	2,741	2,741	2,670	2,162	2,670
MRE (unitless)	1																			
E1		1.0	0.93	0.95	0.00078	0.74	0.40	0.40	0.44	0.56	0.73	0.79	0.83	0.69	0.66	0.45	0.45	0.53	0.67	0.54
E2		1.0	1.4	1.1	0.0093	2.0	1.1	1.1	0.56	2.3	2.1	0.30	0.30	1.1	0.86	0.46	0.46	0.88	0.30	2.1
E1E2		1.0	1.0	1.0	0.00076	0.99	0.04	0.04	0.083	0.93	0.98	0.032	0.050	1.0	0.99	0.089	0.089	0.49	0.012	0.56
Cuttings		1.0	.26	0.79	0.12	0.92	0.40	0.40	0.21	0.22	0.21	0.22	0.94	0.57	0.52	0.30	0.30	0.53	0.54	0.94
Uncertainty E1	2																			
5th Percentile		NA	0.92	0.92	0.0004	0.73	0.40	0.40	0.43	0.55	0.72	0.60	0.83	0.68	0.64	0.44	0.44	0.52	0.26	0.53
95th Percentile			0.94	0.96	0.0012	0.78	0.42	0.42	0.47	0.59	0.78	0.81	0.84	0.72	0.69	0.47	0.47	0.56	0.68	0.55
Uncertainty E2	2																			
5th Percentile		NA	0.61	0.75	0.0009	0.31	0.18	0.18	0.091	0.45	0.37	0.009	0.009	0.19	0.14	0.03	0.03	0.16	0.005	0.33
95th Percentile			2.08	1.75	0.0549	1.39	1.09	1.09	0.87	2.35	2.06	0.83	0.84	1.08	1.61	0.88	0.88	1.62	0.75	2.18
Uncertainty E1E2	2																			
5th Percentile		NA	1.0	1.0	0.0003	0.39	0.009	0.009	0.011	0.37	0.98	0.012	0.012	0.37	0.22	0.01	0.01	0.024	0.009	0.024
95th Percentile			1.0	1.0	0.0066	0.99	0.75	0.75	0.98	0.98	0.98	0.438	0.76	1.0	0.99	0.98	0.98	0.99	0.045	0.99
Uncertainty Cuttings	2																			
5th Percentile		NA	0.25	0.75	0.11	0.91	0.40	0.40	0.21	0.21	0.21	0.21	0.94	0.56	0.52	0.29	0.29	0.53	0.53	0.93
95th Percentile			0.26	0.80	0.18	0.92	0.40	0.40	0.21	0.22	0.21	0.22	0.94	0.57	0.52	0.30	0.30	0.53	0.54	0.94
WIPP Worker Rad Risk	3																			
FTE-Rem		322.85	322.85	322.85	322.85	345.27	357.23	357.23	342.07	340.15	343.99	338.23	339.29	322.85	346.77	366.20	343.78	342.28	339.29	342.28
Excess Fatalities		0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.14	0.15	0.14	0.14	0.14	0.14
WIPP Indust. Accidents	3																			
Injuries		53.63	44.05	44.05	33.20	64.50	70.81	70.81	55.53	49.80	51.77	51.06	66.45	53.63	67.04	69.14	69.56	61.83	63.25	62.53
Fatalities		0.16	0.13	0.13	0.10	0.29	0.30	0.30	0.15	0.15	0.15	0.25	0.28	0.16	0.39	0.21	0.49	0.18	0.28	0.18

TABLE E-3 (continued)

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Waste Processing Risk **Centralized Scenario**	3																			
Off-site Population																				
Cancer Fatalities		$1.94x10^{-4}$	$4..24x10^{-4}$	$4.24x10^{-4}$	$8.99x10^{-1}$	NA	NA	NA	$4..24x10^{-4}$	$4..24x10^{-4}$	$4..24x10^{-4}$	$4..24x10^{-4}$	NA	$4..24x10^{-4}$	$4..24x10^{-4}$	$4..24x10^{-4}$	$4..24x10^{-4}$	$4..24x10^{-4}$	$4..24x10^{-4}$	NA
Cancer Incidence		$5.51x10^{-8}$	$5.74x10^{-7}$	$5.74x10^{-7}$	$3.39x10^{-7}$				$5.74x10^{-7}$	$5.74x10^{-7}$	$5.74x10^{-7}$	$5.74x10^{-7}$		$5.74x10^{-7}$	$5.74x10^{-7}$	$5.74x10^{-7}$	$5.74x10^{-7}$	$5.74x10^{-7}$	$5.74x10^{-7}$	
Workers																				
Cancer Fatalities		$7.78x10^{-1}$	$1.10x10^{+0}$	$1.20x10^{+0}$	$1.34x10^{+0}$				$1.10x10^{+0}$	$1.10x10^{+0}$	$1.10x10^{+0}$	$1.10x10^{+0}$		$1.20x10^{+0}$	$1.20x10^{+0}$	$1.20x10^{+0}$	$1.20x10^{+0}$	$1.20x10^{+0}$	$1.20x10^{+0}$	
Cancer Incidence		$1.30x10^{-5}$	$3.49x10^{-5}$	$3.80x10^{-5}$	$1.69x10^{-4}$				$3.49x10^{-5}$	$3.49x10^{-5}$	$3.49x10^{-5}$	$3.49x10^{-5}$		$3.80x10^{-5}$	$3.80x10^{-5}$	$3.80x10^{-5}$	$3.80x10^{-5}$	$3.80x10^{-5}$	$3.80x10^{-5}$	
Construct/Op Fatalities		2.81	3.79	4.08	5.29				3.79	3.79	3.79	3.79		4.08	4.08	4.08	4.08	4.08	4.08	
Waste Processing Risk **Regionalized Scenario**	3																			
Off-site Population		$1.94x10^{-4}$	$2.73x10^{-4}$	$2.73x10^{-4}$	$4.79x10^{+0}$	NA	NA	NA	$2.73x10^{-4}$	$2.73x10^{-4}$	$2.73x10^{-4}$	$2.73x10^{-4}$	NA	$2.73x10^{-4}$	$2.73x10^{-4}$	$2.73x10^{-4}$	$2.73x10^{-4}$	$2.73x10^{-4}$	$2.73x10^{-4}$	NA
Cancer Fatalities		$5.51x10^{-8}$	$3.69x10^{-7}$	$3.69x10^{-7}$	$3.19x10^{-7}$				$3.69x10^{-7}$	$3.69x10^{-7}$	$3.69x10^{-7}$	$3.69x10^{-7}$		$3.69x10^{-7}$	$3.69x10^{-7}$	$3.69x10^{-7}$	$3.69x10^{-7}$	$3.69x10^{-7}$	$3.69x10^{-7}$	
Cancer Incidence																				
Workers		$7.78x10^{-1}$	$9.92x10^{-1}$	$8.12x10^{-1}$	$9.10x10^{-1}$				$9.92x10^{-1}$	$9.92x10^{-1}$	$9.92x10^{-1}$	$9.92x10^{-1}$		$8.12x10^{-1}$	$8.12x10^{-1}$	$8.12x10^{-1}$	$8.12x10^{-1}$	$8.12x10^{-1}$	$8.12x10^{-1}$	
Cancer Fatalities		$1.30x10^{-5}$	$3.15x10^{-5}$	$2.58x10^{-5}$	$3.73x10^{-5}$				$3.15x10^{-5}$	$3.15x10^{-5}$	$3.15x10^{-5}$	$3.15x10^{-5}$		$2.58x10^{-5}$	$2.58x10^{-5}$	$2.58x10^{-5}$	$2.58x10^{-5}$	$2.58x10^{-5}$	$2.58x10^{-5}$	
Cancer Incidence		2.81	3.83	3.45	7.18				3 83	3.83	3 83	3 83		3.45	3.45	3.45	3.45	3.45	3.45	
Construct/Op Fatalities																				
Waste Processing Risk **Decentralized Scenario**	3																			
Off-site Population		$1.94x10^{-4}$	$2.65x10^{-4}$	$2.65x10^{-4}$	$4.60x10^{+0}$	NA	NA	NA	$2.65x10^{-4}$	$2.65x10^{-4}$	$2.65x10^{-4}$	$2.65x10^{-4}$	NA	$2.65x10^{-4}$	$2.65x10^{-4}$	$2.65x10^{-4}$	$2.65x10^{-4}$	$2.65x10^{-4}$	$2.65x10^{-4}$	NA
Cancer Fatalities		$5.51x10^{-8}$	$3.59x10^{-7}$	$3.59x10^{-7}$	$3.06x10^{-7}$				$3.59x10^{-7}$	$3.59x10^{-7}$	$3.59x10^{-7}$	$3.59x10^{-7}$		$3.59x10^{-7}$	$3.59x10^{-7}$	$3.59x10^{-7}$	$3.59x10^{-7}$	$3.59x10^{-7}$	$3.59x10^{-7}$	
Cancer Incidence																				
Workers		$7.78x10^{-1}$	$9.54x10^{-1}$	$7.91x10^{-1}$	$1.17x10^{+0}$				$9.54x10^{-1}$	$9.54x10^{-1}$	$9.54x10^{-1}$	$9.54x10^{-1}$		$7.91x10^{-1}$	$7.91x10^{-1}$	$7.91x10^{-1}$	$7.91x10^{-1}$	$7.91x10^{-1}$	$7.91x10^{-1}$	
Cancer Fatalities		$1.30x10^{-5}$	$3.03x10^{-5}$	$2.51x10^{-5}$	$4.81x10^{-5}$				$3.03x10^{-5}$	$3.03x10^{-5}$	$3.03x10^{-5}$	$3.03x10^{-5}$		$2.51x10^{-5}$	$2.51x10^{-5}$	$2.51x10^{-5}$	$2.51x10^{-5}$	$2.51x10^{-5}$	$2.51x10^{-5}$	
Cancer Incidence		2.81	4.05	3.78	9.73				4.05	4.05	4.05	4 05		3.78	3.78	3.78	3.78	3.78	3.78	
Construct/Op Fatalities																				
Mining Advance Rate (m/Shift)	4	1.8	1.8	1.8	1.9	2.0	1.9	1.9	4 2	4.5	4.5	4.2	1.9	1.8	2.0	1.9	1.9	2.0	1.9	2.0
Removal Risk	4																			
Fatal Accidents		0 58	0.58	0 58	0.58	0 53	0 56	0 56	0 26	0.24	0 24	0 25	0.56	0.58	0.53	0.56	0 56	0.53	0.55	0.53
Non-Fatal Accidents		11.74	11.66	11 73	11.62	10 74	11 31	11.31	5.15	4.83	4 83	5 09	11.22	11.69	10.69	11.26	11 26	10.69	11.17	10.74

TABLE E-3 (continued)

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Trans Rad Risk[1] **Decentralized** (CH only)	5																			
Worker																				
Person-Rem		$6.69x10^{+2}$	$5.81x10^{+2}$	$5.47x10^{+2}$	$7.16x10^{+2}$	$6.69x10^{+2}$	$6.69x10^{+2}$	$6.69x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$6.69x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$6.69x10^{+2}$
LCF		$2.68x10^{-1}$	$2.32x10^{-1}$	$2.19x10^{-1}$	$2.86x0^{-1}$	$2.68x10^{-1}$	2.6810^{-1}	2.6810^{-1}	$2.32x10^{-1}$	$2.32x10^{-1}$	$2.32x10^{-1}$	$2.32x10^{-1}$	2.6810^{-1}	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	2.6810^{-1}
Public																				
Person-Rem		$4.00x10^{+3}$	$3.47x10^{+3}$	$3.27x10^{+3}$	$4.27x10^{+3}$	$4.00x10^{+3}$	$4.00x10^{+3}$	$4.00x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$4.00x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$4.00x10^{+3}$
LCF		$2.00x10^{+0}$	$1.74x10^{+0}$	$1.64x10^{+0}$	$2.14x10^{+0}$	$2.00x10^{+0}$	$2.00x10^{+0}$	$2.00x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$2.00x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$2.00x10^{+0}$
Accident																				
Person-Rem		$8.01x10^{+1}$	$5.92x10^{+0}$	$7.59x10^{+1}$	$1.21x10^{+0}$	$8.01x10^{+1}$	$8.01x10^{+1}$	$8.01x10^{+1}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$8.01x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$8.01x10^{+1}$
LCF		$4.01x10^{-2}$	$2.96x10^{-3}$	$3.80x10^{-2}$	$6.05x10^{-4}$	$4.01x10^{-2}$	$4.01x10^{-2}$	$4.01x10^{-2}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$4.01x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$4.01x10^{-2}$
Trans Chemical Risk **Decentralized**	5																			
Max. Individual		$1.21x10^{+0}$	$1.80x10^{+0}$	$1.20x10^{+0}$	$2.10x10^{-5}$	$1.21x10^{+0}$	$1.21x10^{+0}$	$1.21x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.21x10^{+0}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$1.21x10^{+0}$
Trans Non-Rad/Chem Risk **Decentralized**	5																			
Injuries		$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$
Fatalities		$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$
Percent of Comments Addressed by EA	6	NA	33%	33%	40%	31%	36%	36%	33%	33%	33%	33%	36%	42%	42%	42%	42%	42%	42%	36%
Total System Cost	7																			
Decentralized ($x10^6$)		4,483	5,219	4,955	6,704	4,538	4,569	4,569	5,280	5,250	5,257	5,255	4,536	7,624	7,675	7,703	7,703	7,667	7,673	4,529
Regionalized ($x10^6$)		4,335	4,824	4,607	5,742	4,391	4,421	4,421	4,884	4,855	4,861	4,859	4,388	6,835	6,886	6,913	6,914	6,877	6,883	4,381
Centralized ($x10^6$)		4,029	4,177	4,129	4,725	4,084	4,115	4,145	4,237	4,208	4,214	4,213	4,082	4,982	5,032	5,060	5,061	5,024	5,030	4,075
Schedule Impact - Delayed Emplacement Relative to Baseline Startup	7	No Delay	9yrs.	8yrs.	9yrs.	No Delay	No Delay	No Delay	9yrs.	9yrs.	9yrs.	9yrs.	No Delay	9yrs.	9yrs.	9yrs.	9yrs.	9yrs.	9yrs.	No Delay
Other Waste Generation	8																			
Secondary (m^3)		32,729	118,040	118,040	21,848	32,729	32,729	32,729	118,040	118,040	118,040	118,040	32,729	131,625	131,625	131,625	131,625	131,625	131,625	32,729
LLW/LLMW (m^3)		16,365	59,020	59,020	10,924	16,365	16,365	16,365	59,020	59,020	59,020	59,020	16,365	65,813	65,813	65,813	65,813	65,813	65,813	16,365

[1]Only the Decentralized scenario is shown here. The Centralized scenario results for all EAs are the same as the baseline reported here. The Regionalized scenario analysis output is shown in Table 3-44.

- Waste Processing alternatives (EA # 1,6 & 10) were analyzed for the three processing scenarios (centralized, regionalized, and decentralized). Each scenario has inherent benefits and detriments. In general, processing alternatives impact the entire waste disposal system, involving the generator/storage sites, waste transportation, other waste disposal systems, and the WIPP waste handling system. Processing alternatives have higher cost, greater risks, and present increased schedule delays in comparison to baseline or backfill only EAs. In general, processing EAs have a marginal performance impact on the repository except for plasma processing (EA# 10) which shows a significant increase in repository impact, however, at the expense of the highest potential risk for all of the EAs analyzed.

  Centralized Processing—Since the centralized scenario processes all waste at one facility, the construction and operational costs are the lowest of the three waste processing scenarios. Operational and construction incidents and fatalities and public and worker chemical and radiological exposure risks are higher than the baseline. Transportation impacts are similar to the baseline. The centralized scenario has the highest potential to impact system wide disposal operations. Since one facility processes all waste, this facility becomes a potential choke point for the entire system.

  Regionalized Processing—The regionalized scenario processes waste at five generator/storage sites. The cost to implement regionalized EA scenarios are significantly higher than the centralized and slightly lower than the decentralized scenarios. In general, the worker and public radiological/chemical exposure risks are slightly higher than the centralized and lower than the decentralized scenarios. Transportation chemical exposure risks are slightly lower than the baseline since the waste is processed into a more inert matrix prior to shipment to WIPP. Accident and radiation risks are similar to the baseline.

  Decentralized Processing—For the scenario, processing is performed at the ten major generator/storage sites. The scenario has the highest cost of the three processing scenarios (as much as $1 billion difference between the centralized and decentralized for EA# 77a-d). The operation/construction incidents and fatality rates are generally higher than both the centralized and regionalized (baseline included).

- Backfill alternatives (EA# 33, 35a, 35b, 83 and 111) have the least impact on the entire waste disposal system. The WIPP waste handling system is impacted; waste transportation, generator/storage sites, and other waste disposal systems are not affected. Cost, schedule radiation and chemical exposure are similar to the baseline estimates. Backfill alternatives improve long-term disposal system performance.

- Combination alternatives contain both multiple processing alternatives and/or backfill alternatives. These alternatives (EA# 77a through 77d and 94a through 94f) have benefits and detriments associated with each individual alternative type. The overall cost and schedule impacts are the highest of the EAs. Transportation, worker and public risks (radiological, chemical accidental and incidental) are also the highest of all EAs. The overall impact of combination EAs on long-term disposal system performance are comparable to that associated with the backfill and processing only alternatives.

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WIPP ENGINEERED ALTERNATIVES IMPACT VECTOR ELEMENTS

TRU WASTE DISPOSAL SCENARIO		LONG TERM COMPLIANCE CONFIDENCE		PUBLIC HEALTH RISK				WORKER HEALTH		DISPOSAL SYSTEM COSTS					WIPP SCHEDULE			
						At WIPP				TRU WASTE								
												At WIPP						
Seq. No.	Engineered Alternative Case #	Cutings Scenarios	Water Scenarios	At Generator	In Transport	*Before Closure*	*After Closure*	At Generator	At WIPP	At Generator	In Transport	*Storage & Treatment*	Placement & Backfill	IMPACT ON OTHER WASTE DISPOSAL SYSTEMS	First Waste	Closure	WASTE REMOVAL CAPABILITY	PUBLIC ACCEPTANCE
1	Baseline-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
2	33-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
3	35a-1	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
4	35b-1	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
5	111-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
6	83-1	▲	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
7	1-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	○	□	■	▲	○	▲
8	77a-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	▲	□	■	▲	○	▲
9	77b-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	▲	□	■	▲	○	▲
10	77c-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	▲	□	■	▲	○	▲
11	77d-1	○	○	▲	▲	□	▲	▲	■	▲	▲	■	▲	□	■	▲	○	▲
12	6-1	▲	▲	▲	▲	□	▲	▲	■	○	▲	■	○	□	■	▲	▲	▲
13	94a-1	○	▲	▲	▲	□	▲	▲	■	○	▲	■	▲	□	■	▲	▲	▲
14	94b-1	○	▲	▲	▲	□	▲	▲	■	○	▲	■	□	□	■	▲	▲	▲
15	94c-1	○	▲	▲	▲	□	▲	▲	■	○	▲	■	□	□	■	▲	▲	▲
16	94d-1	○	▲	▲	▲	□	▲	▲	■	○	▲	■	□	□	■	▲	▲	▲
17	94e-1	○	▲	▲	▲	□	▲	▲	■	○	▲	■	□	□	■	▲	▲	▲
18	94f-1	○	○	▲	▲	□	▲	▲	■	○	▲	■	□	□	■	▲	▲	▲
19	10-1	●	●	▲	▲	■	▲	▲	■	○	▲	■	○	○	■	▲	▲	▲

SCENARIO TREE LEGEND:

- Super C: Supercompaction of all waste, except sludges
- S&C: Shreding and compaction of all waste, except sludges
- SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
- SAG: Salt Aggregate Grout
- CG: Cemenitious Grout

IMPACT VECTOR RANKING:

- ● Performance is significantly better than the corresponding baseline performance.
- ○ Performance is marginally better than the corresponding baseline performance.
- ▲ Performance is approximately the same as the corresponding baseline performance.
- □ Performance is marginally worse than the corresponding baseline performance.
- ■ Performance is significantly worse than the corresponding baseline performance.

[a] The Centralized Processing Scenario was selected because it generally produces the lowest increase in cost, schedule impacts, and health risks with respect to the baseline case–results for the regionalized and decentralized scenarios are found in Section 3.0.

Figure E-4
Summary of WIPP Engineered Alternative Evaluation Results for Centralized Processing Scenario[a]

DOE/WIPP 95-2135 10/13/95

TABLE OF CONTENTS

TABLE OF CONTENTS *(Continued)*

TABLE OF CONTENTS *(Continued)*

TABLE OF CONTENTS *(Continued)*

TABLE OF CONTENTS *(Continued)*

LIST OF FIGURES

LIST OF FIGURES *(Continued)*

LIST OF FIGURES *(Continued)*

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LIST OF TABLES

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LIST OF ABBREVIATIONS/ACRONYMS

Am	americium
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
BIR	Baseline Inventory Report
CaO	calcium oxide
CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
CH	contact-handled
Ci	curie
CPLM	costs per loaded mile
CPM	critical path method
DAM	Design Analysis Model
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DOE-CAO	U.S. Department of Energy, Carlsbad Area Office
DOT	U.S. Department of Transportation
DRZ	disturbed rock zone
EA	*Engineered Alternative*
EACBS	Engineered Alternatives Cost Benefit Study
EAMP	Engineered Alternatives Multidisciplinary Panel
EASWG	Engineered Alternatives Study Working Group
EATF	Engineered Alternatives Task Force
EM-PEIS	Environmental Management Programmatic Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ERPG-2	Emergency Response Planning Guideline-2
ETEC	Energy Technology Engineering Center
FEIS	Final Environmental Impact Statement
FSEIS	Final Supplement Environmental Impact Statement
FTE	full-time equivalent
IDB	Integrated Data Base
INEL	Idaho National Engineering Laboratory
IR	incident rate(s)
KAPL	Knolls Atomic Power Laboratory
LANL	Los Alamos National Laboratory
lb/ft^3	pounds per cubic meter
LBL	Lawrence Berkeley Laboratory
LCF	latent cancer fatality
LESAT	Lockheed Martin Environmental Systems and Technologies Co.
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
LOC(s)	level(s) of concern
LWA	Land Withdrawal Act
m^3	cubic meter
MB139	Marker Bed 139

LIST OF ABBREVIATIONS/ACRONYMS *(Continued)*

MEI	Maximum Exposed Individual
MOI	Maximum Off-Site Individual
MPa	megaPascals
m/s	meters per second
MRE	Measure of Relative Effectiveness
mrem/hr	millirem per hour
MU	Missouri University
MWIR	(Interim) Mixed Waste Inventory Report
NACEPT	National Advisory Council on Environmental Policy and Technology
nCi/g	nanoCuries per gram
NEPA	National Environmental Policy Act
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
OASIS	*Organic and Sludge Immobilization System*
O&M	operations and maintenance
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
PA	Performance Assessment
PACT	Plasma Arc Centrifugal Treatment
PDSTP	Preliminary Draft Site Treatment Plan
PEL	permissible exposure limit
PERT	Project Evaluation and Review Technique
PLCC	planning life cycle cost
PPE	personal protective equipment
preops	preoperations
psi	pounds per square inch
Pu	plutonium
QAPP	Quality Assurance Program Plan
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RH	remote-handled
SARF	Supercompaction and Repackaging Facility
SEIS	Supplement Environmental Impact Statement
SNL/NM	Sandia National Laboratories/New Mexico
SPM	System Prioritization Method
SRS	Savannah River Site
SVOC	semivolatile organic compound
SWB	standard waste box
Th	thorium
TI	Transport Index
TLV(s)	threshold limit value(s)
TRU	transuranic
TRUPACT-II	Transuranic Package Transporter-II
U	uranium

LIST OF ABBREVIATIONS/ACRONYMS *(Continued)*

VOC	volatile organic compound
WAC	Waste Acceptance Criteria
WID	Westinghouse Waste Isolation Division
WIPP	Waste Isolation Pilot Plant
WMFCITRUW	Waste Management Facility Cost Information for Transuranic Waste
WSRIC	(RFETS) Waste Stream and Residue Identification and Characterization

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

An Engineered Alternative (EA) is defined as a technologically feasible process, technology, method, repository design, or waste form modification which makes a significant positive impact on the disposal system, and in general terms, as an engineered barrier or group of engineered barriers. A "Barrier" is defined in Title 40, Code of Federal Regulations (CFR) Part 191 (40 CFR 191) as,

> "...any material or structure that prevents or substantially delays movement of water or radionuclides towards the accessible environment. For example, a barrier may be a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around the waste, provided that the material or structure substantially delays movement of water or radionuclides" (EPA, 1993a).

An engineered barrier is further defined in the Waste Isolation Pilot Plant (WIPP) Land Withdrawal Act (LWA) as,

> "...backfill, room seals, panel seals, and any other manmade barrier component of the disposal system" (U.S. Congress, 1992).

Both natural and engineered barriers are presently incorporated in the disposal system design of WIPP. EAs may be used to provide additional confidence that the WIPP disposal system will comply with the containment requirements in 40 CFR 191. This additional confidence measure defines the term assurance used throughout this report.

The Department of Energy (DOE) has initiated this EA cost benefit study (EACBS) to provide a technical basis for the selection and rejection of EAs for the WIPP should it be determined that additional barriers are needed for assurance purposes. This study includes a qualitative assessment of estimated costs, potential risks, benefits, and relative repository performance impacts resulting from the implementation of EAs. This assessment was made by first identifying candidate EAs and then screening alternatives using a defined process to determine which EAs should be retained for further detailed analysis. The detailed analyses were designed and conducted so as to determine the relative benefits and detriments on the DOE transuranic (TRU) waste management system. Performance related benefits at WIPP were considered, but were not the only impacts assessed. The results of the study will provide DOE with cost and benefit information for use in the selection of additional engineered barriers for the WIPP if it is determined to be desirable.

The selection/rejection of EAs for use at WIPP will be made using the best available information and will take into consideration the importance of many relevant factors. Examples of these factors are disposal system performance, cost, and risk to the public and workers from radiological/chemical and transportation related incidents and accidents. Since the relative benefit of an EA is dependent on those factors that carry the most importance, which are determined by the DOE decision maker, this study does not quantitatively rank nor recommend EAs for possible use at WIPP. The EACBS provides non-weighted information and, where possible, qualitatively compares an EA's impact with respect to the existing baseline for WIPP.

1.2 BACKGROUND

1.2.1 WIPP Description and Mission Statement

The WIPP, a research and development facility of the DOE, is located in the Northern Delaware Basin in southeastern New Mexico (Figure 1-1). The WIPP is a proposed underground repository designed and constructed for the disposal of TRU radioactive wastes. TRU wastes are generated from DOE defense-related activities, including weapons production research, and development. Currently, the majority of these wastes are generated and/or stored at ten DOE sites across the country (DOE, 1994c).

The majority of TRU waste is material contaminated with alpha emitting radionuclides (e.g., plutonium-239) with half lives greater than 20 years and concentrations greater than 100 nanocuries per gram (nCi/g) of waste (DOE, 1994c). TRU wastes are classified as either contact-handled (CH) or remote-handled (RH) (DOE, 1994c), depending on the dose rate at the surface of the waste container. CH-TRU waste containers have an external dose rate less than 200 millirem per hour (mrem/hr) at the surface of the container. CH-TRU waste constitutes the vast majority (~97 volume percent) (DOE, 1995e) of the overall TRU waste inventory destined for WIPP. The WIPP repository and the waste to be stored at WIPP are described below.

1.2.1.1 The WIPP Repository

Detailed descriptions of the geology and hydrology of the WIPP site have been published in numerous documents (DOE, 1990b; Lappin, 1988; Lappin et al., 1989). The WIPP repository is located 2,150 feet below the surface in a bedded salt (halite) formation of Permian age known as the Salado Formation (Figure 1-2). The basis for the selection of the WIPP site and an analysis of its environmental impacts were presented in the WIPP Final Environmental Impact Statement (FEIS) (DOE, 1980) and supplemented with more current information in the Final Supplement Environmental Impact Statement (FSEIS) (DOE, 1990b). Figure 1-3 shows a three-dimensional layout of the repository in relation to the support facilities on the surface. The WIPP rooms and panels are excavated in the salt beds of the Salado. A panel consists of seven waste emplacement rooms and associated access drifts as shown in Figure 1-3.

After the waste is emplaced in the WIPP disposal rooms, natural closure occurs due to the creep (plastic flow) of the surrounding salt formation. This creep is in response to the pressure gradient that exists between the far-field pressure away from the repository (referred to as the lithostatic pressure or the pressure at the depth of the repository due to overlying rock) and the pressure in the repository (which, after excavation, is initially at atmospheric pressure). In a freshly excavated room under atmospheric pressure, this creep is of the order of a few inches per year. Under expected conditions, complete closure of the repository occurs, and the waste is safely and permanently isolated from the surrounding environment.

1.2.1.2 Waste Description

TRU waste to be disposed of at the WIPP consists of newly generated and/or retrievably stored waste in drums or boxes at major DOE facilities across the United States. Examples of

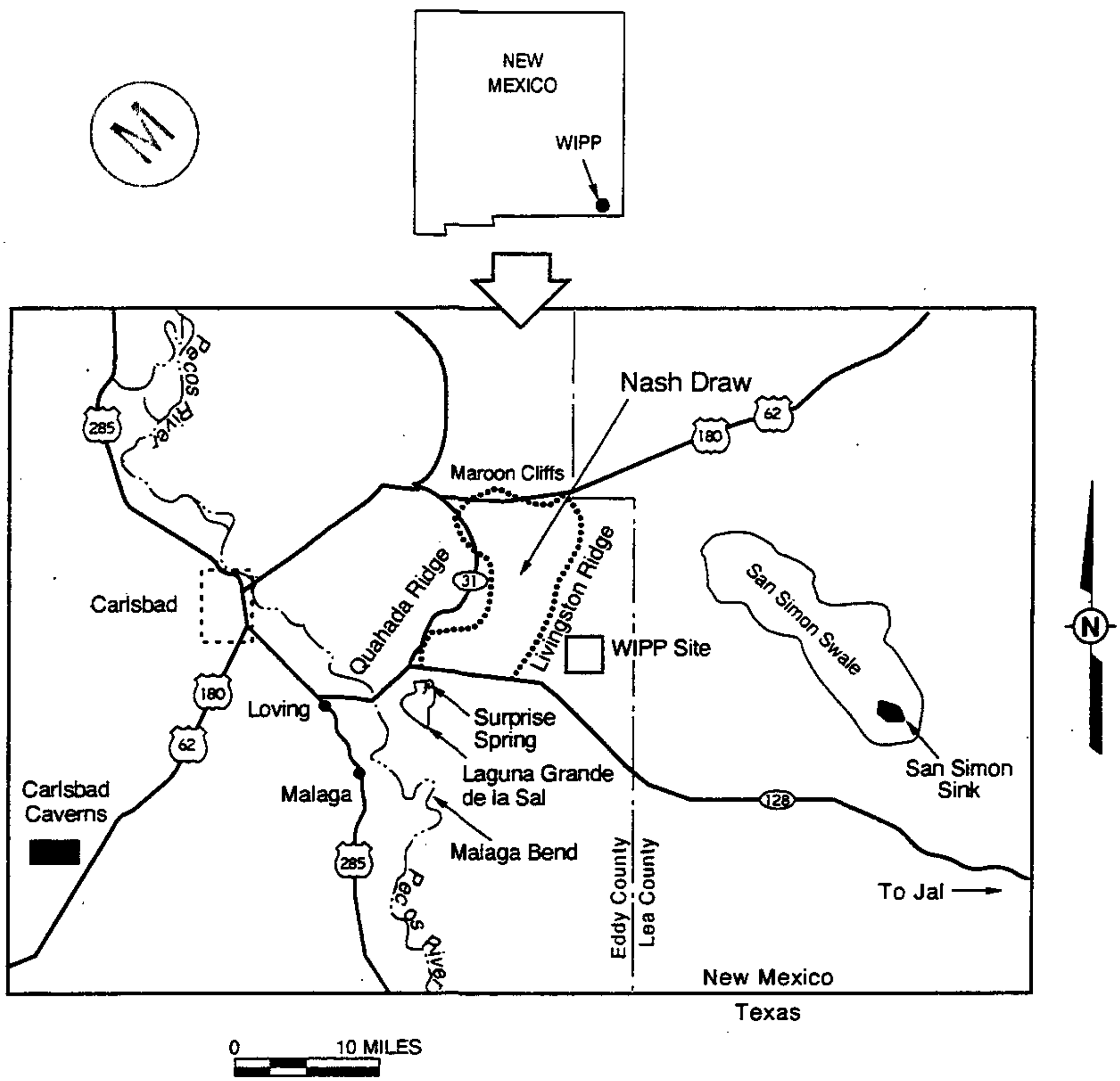

Figure 1-1
WIPP Location in Southeastern New Mexico (Rechard, 1989)

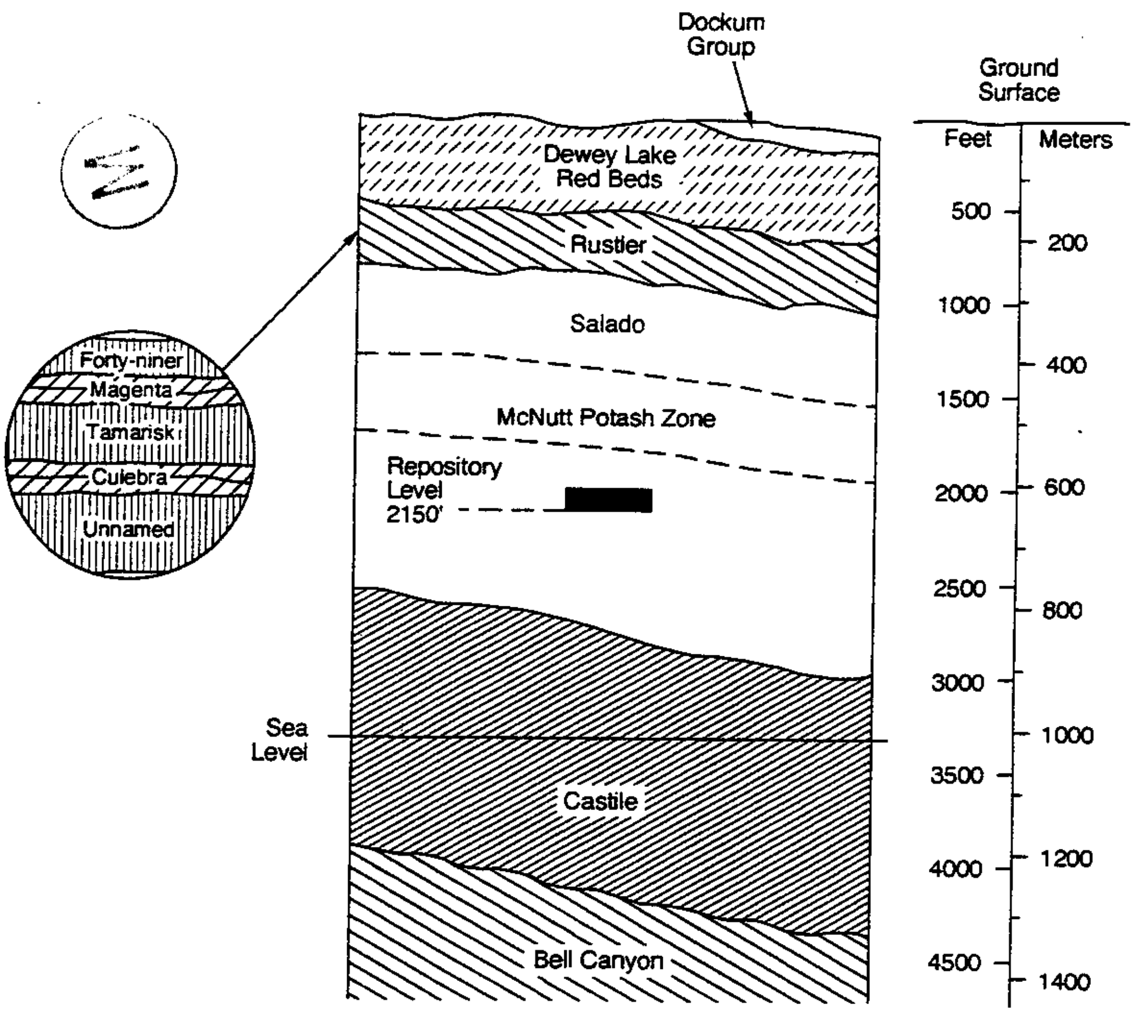

Figure 1-2
Level of WIPP Repository and Generalized Stratigraphic Column (Rechard, 1989)

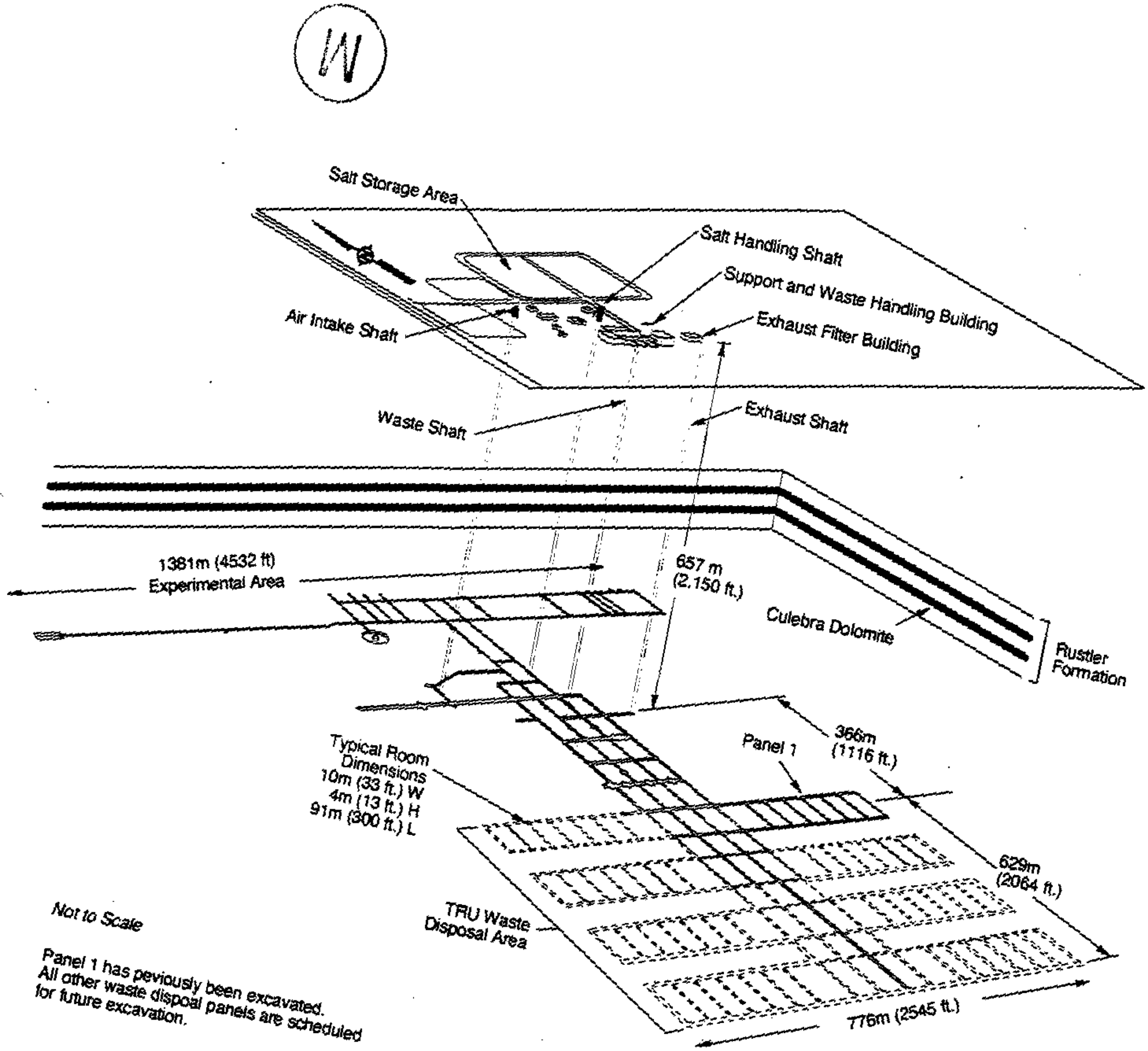

Figure 1-3

Proposed WIPP Repository Showing Both TRU Disposal Areas and Experimental Areas (Nowak et al., 1990)

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processes that generate the waste are plutonium recovery operations, glove box operations, and the operation of on-site analytical and research and development laboratories. The waste destined for the WIPP site is either solid or solidified material and can be grouped into three major waste forms:

- Sludges
- Solid organic (combustible) waste
- Solid inorganic (glass/metal, etc.) waste.

Sludges are predominantly inorganic solidified wastes with some form of solidifying or stabilizing agent, usually a cement-based material. A small percentage of sludges designated as "organic sludges" may contain organic solvents in greater than trace (>1 weight percent) quantities (DOE, 1994f). Solid organic waste consists of organic materials (sometimes referred to as "combustible" waste) such as paper, plastic, tissues, plywood, etc. Solid inorganic waste consists of metals, glass, and a small percentage of other noncombustible material. All waste types are in a chemically stable and nonreactive form (DOE, 1990c) and have been stored and handled at the waste generator and disposal sites for over four decades. The wastes generated at the different sites are generally comparable, and for the most part, can all be grouped under the three waste forms listed above (DOE, 1990c).

The waste is generally packaged in plastic bags (polyethylene and/or polyvinyl chloride) that are placed inside the waste containers (55-gallon steel drums or larger metal boxes) (DOE, 1994f). These different layers of confinement serve as barriers for radioactive materials in the waste. The waste containers are fitted with carbon composite filters to prevent the build-up of gas pressure in the containers, while retaining any particulates inside the containers (NRC, 1994).

Waste characterization (the constituents and properties) of TRU waste is based on process knowledge and records information, and information from past and current sampling programs in place at the DOE sites. The available waste characterization information has been comprehensively summarized in a number of documents (e.g., DOE, 1995e, DOE, 1994f; DOE, 1990c).

1.2.2 Past EA and Related Studies

Prior to the DOE initiating this cost benefit study, designed to provide additional information for use in selecting or rejecting EAs for the WIPP, Performance Assessment (PA) (SNL, 1993), EA effectiveness and feasibility studies (DOE, 1991a), and other repository performance studies have been conducted at WIPP.

Preliminary performance assessment analyses of the WIPP's long-term performance undertaken in the late 1980s indicated that two potential problems could lead to the inability of demonstrating compliance: (1) gas generation in the repository leading to excess pressure that could serve as a driving force for transport to the boundary, and (2) future inadvertent human intrusion events. The identification of these problems led to a list of associated performance parameters and an associated list of design enhancements including modifications to the facility, to the waste forms, and/or other design variations. These candidate design enhancements are referred to as engineered alternatives and were evaluated for their feasibility of reducing or eliminating gas generation and/or the consequences of human intrusion events. An evaluation of the risk to human health was not part of this PA assessment.

The DOE established the Engineered Alternatives Task Force (EATF) in September of 1989, and chartered it to identify and screen potential EAs with respect to both effectiveness and feasibility of implementation to address the concerns about gas generation and human intrusion. The EATF, in turn, chartered an Engineered Alternatives Multidisciplinary Panel (EAMP) which screened an initial 64 alternatives to 36. The EATF then combined these candidates into 14 logically consistent and potentially viable "engineered alternatives." These 14 candidates, plus a baseline, were evaluated with respect to relative effectiveness and feasibility in addressing gas generation and inadvertent human intrusion impacts. The EATF issued its final report in July 1991 (DOE, 1991a). In order to maximize the benefits of the EATF evaluations and to provide timely integration of EATF activities with SNL PA, these programs were conducted in parallel. The overall purpose of the alternatives evaluation by the EATF was to enhance performance of the WIPP to meet regulatory requirements for containment.

This EACBS differs from the EATF study in two fundamental ways. First, in the current study, EAs are assessed against eight specific factors (as prescribed in 40 CFR 194) that provide the data and information for use in selecting or rejecting an EA based on a set of screening criteria. Second, the 1991 EATF study was aimed at identifying alternatives which, if needed, would improve disposal system performance to the point where compliance with quantifiable standards was achieved. The current study begins with the assumption that regulatory compliance can be demonstrated with the current baseline and that these alternatives could be used to enhance the performance of the WIPP disposal system through treatment of the uncertainty about the qualitative performance predictions.

1.2.3 Regulatory Topics

The WIPP disposal system must demonstrate compliance with the requirements imposed by several regulations. The DOE must demonstrate compliance with Subparts B and C of 40 CFR 191. These regulations call for a PA to be used to predict the expected cumulative releases of radionuclides to the accessible environment over 10,000 years. The PA uses numerical modeling to predict whether the performance of the disposal system can reasonably be expected to meet the requirements of 40 CFR 191. The numerical modeling is supported by experimental programs and expert judgement as appropriate. Results of the PA are quantitative in nature and will indicate whether the WIPP design meets the numerical performance measures specified in the 40 CFR 191 standard. Therefore, the calculated results of a final PA can only be used to indicate that the disposal system does or does not comply. This point is important because the results of the EACBS are not in a form that will lend themselves to such comparative analysis using alternative PA results.

The 40 CFR 191 regulations also specify that assurance measures will be implemented at WIPP. These assurance measures provide additional confidence and thereby complement compliance with the containment requirements of 40 CFR § 191.13. Assurance measures planned for the WIPP include active institutional controls, monitoring, passive institutional controls, and both natural and engineered barriers. Natural and engineered barriers that are currently part of the baseline include the favorable geology; hydrology, and the shaft sealing system. The EACBS was designed to identify candidate EAs that could be used to address the assurance requirements by providing the information necessary to allow a decision for their use beyond that necessary to meet the regulatory containment requirements. As part of the assurance requirements, EAs may be complementary to the numerical performance predictions by adding confidence to prediction of the disposal system performance through treatment of the uncertainty associated with the calculated performance prediction.

A distinction between compliance with the numerical requirements for containment and assurance must be maintained. Compliance relates to the regulatory performance limits applicable to the WIPP, whereas assurance relates to enhancing performance or reducing uncertainty associated with a compliance determination. This study assumes the baseline repository design is compliant with all 40 CFR 191 requirements. If an EA is selected by the DOE based on information in this report, utilization of the EA will be in addition to the engineered barriers already incorporated in the baseline.

1.3 PROGRAM DRIVERS

This study is intended to provide potential valuable measures to be used for enhancing repository performance or reducing uncertainty associated with a compliance determination should the DOE determine that such steps are justifiable. A proactive approach was used through the assessment of recent DOE, EPA, and NACEPT interactions that concluded that investigating the potential benefits and detriments of additional engineered barriers is a logical and responsible endeavor.

2.0 PROGRAM APPROACH

2.1 METHOD USED TO ANALYZE ENGINEERED ALTERNATIVES

The EACBS uses a multi-step process to assess and analyze EAs. The basic approach identifies EAs to be considered in the analysis, screens this list to determine that the EA meets specific criteria, and then analyzes each EA in a multifactor analysis producing cost, scheduling, and benefit/detriment information. This process is illustrated in Figure 2-1 and is described further in this section.

The EACBS is composed of these five basic components.

- Identify Potential Engineered Alternatives—A list of potential engineered alternatives is generated. The list is composed of potentially viable alternatives from previous studies and stakeholder input. This list is found in Appendix A.

- Screen Engineered Alternatives—EAs were screened to eliminate alternatives that did not meet a specified criterion for system benefit or detriment. A multidisciplinary working group was used to define the criteria and screen the alternatives. The result of the screening process was a list of potential EAs to include in the cost/benefit analysis and a list of EAs that were rejected from further evaluation. Those EAs that were rejected were qualified with the reason for rejection. The EAs and the reasons for rejection are found in Appendices B and C.

- Optimize Remaining Engineered Alternatives—The EAs that passed the screen were optimized based on technological feasibility and effectiveness to determine the set of EAs for use in the EACBS.

- Analyze Optimized EAs against Eight Factors—The optimized list of EAs were analyzed against the eight factors prescribed in Section 1.0. The output of the analysis was compiled and summarized. The methods, processes, and assumptions used in the analyses were documented.

- Summarize Results—A complete summary of the factor analysis output is presented. The output of the study compares the results from the EA analysis with respect to the baseline.

The EA screening and selection process was designed to allow EAs, from any source, to be considered and independently evaluated. If an EA was to be further analyzed, the EA was independently assessed and documented with respect to each of the eight factors. This approach was taken to ensure that the EACBS would not be influenced by the source of the EAs, the number of EAs analyzed, or their performance. It also ensures that the analysis would be repeatable which allows additional EAs to be analyzed in the future.

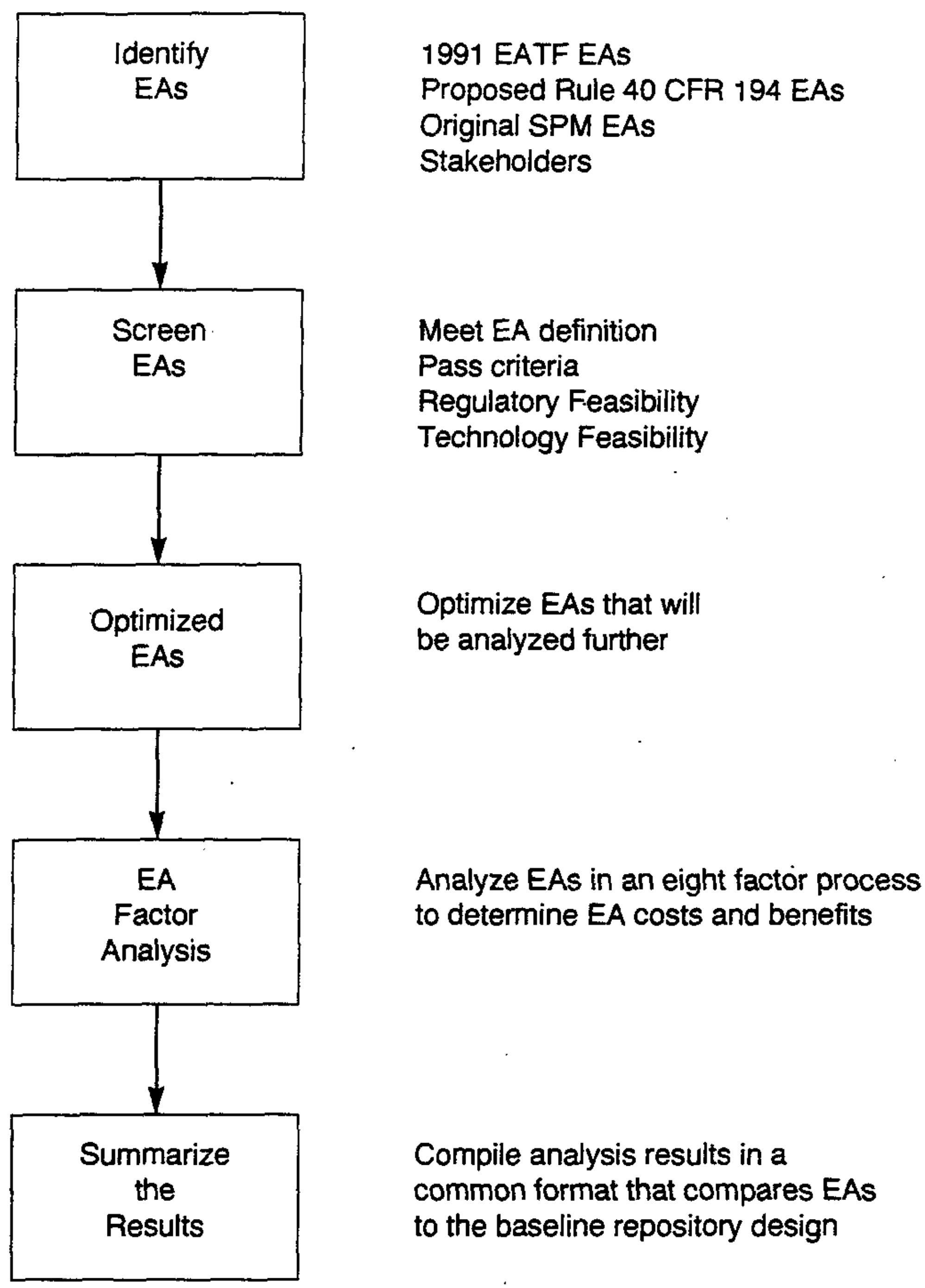

Figure 2-1
EACBS Program Flow Chart

The EACBS identifies potentially valuable measures by analyzing EAs with respect to the following factors:[1]

1. Effects of EAs on long-term performance of the disposal system—This factor analyzes the EA's ability to limit water and radionuclide movement towards the accessible environment and the consequences of human initiated processes or events (human intrusion).

2. The increased or reduced uncertainty in compliance assessment

3. Impact on public and worker exposures to radiation (at the WIPP and off site) both during and after incorporation of an EA

4. The increased ease or difficulty in future removal of the waste from the WIPP disposal system

5. The increased or reduced risk of transporting the waste to the WIPP (radiation and chemical exposures, incidental and accidental)

6. The increased or reduced public confidence in the performance of the disposal system

7. The increased or reduced total DOE waste management system cost and schedule impacts

8. The impact on other waste disposal programs from the incorporation of an EA.

In addition to the factors listed above, the EACBS includes analyses which evaluated:

- Existing waste that is already packaged
- Existing waste that is not yet packaged
- Existing waste that is in need of repackaging
- To-be-generated waste.

2.2 IDENTIFICATION AND SCREENING OF ENGINEERED ALTERNATIVES

2.2.1 Engineered Alternatives Identification

A list of candidates was compiled from the previous EA studies and the proposed rule 40 CFR 194. The list includes the following.

- Sixty-four individual EAs, 14 EA combinations and a baseline found in the Final Report of the Engineered Alternatives Task Force (DOE, 1991a). These are the individual technologies and combinations considered in the original EATF study.

[1]These evaluation factors are prescribed in the EPA proposed rule 40 CFR Part 194. However, Factors 1 and 9 as listed in 40 CFR 194 have been combined in the EACBS.

- Twenty EAs initially considered in the System Prioritization Methodology (SPM).

- Ten EAs found in the proposed rule 40 CFR §194.44.

- Stakeholder input from focus group and technical exchange meetings.

A complete list of the initial EAs can be referenced in Appendix A and was used as input for the screening process. Each EA is identified by a unique number that is used throughout the entire study. During the screening process, selected EAs were refined to allow more detailed evaluation of the results with respect to the technologies associated with the specific EA. These EAs used the same assigned number as the original but a lower case letter was added. This allowed changes to be tracked throughout the study. An example includes EA# 4—Wet Oxidation. The Engineered Alternatives Screening Working Group (EASWG) determined that wet oxidation alone was not a viable EA in and of itself because the resulting treated waste would need to be solidified to be shippable and accepted at WIPP. For this reason, EA # 4 was split into 4a—Wet Oxidation and Cement Solid Organics and 4b—Wet Oxidation and Vitrify Solid Organic Waste. In addition to those EAs passing the screening process, the EASWG added two EAs to the list.

Formal requests were made by the DOE to WIPP stakeholders to provide input into the screening process. During the development of the EACBS, stakeholders suggested EAs, such as vitrification and alternate container materials, for consideration in the EACBS. No new EAs were suggested by stakeholders that were not already being considered in the study.

2.2.2 Screening Process

A two-tiered approach was used to screen the initial list of EAs. The first tier consisted of qualitatively comparing conceptual technologies to a precise definition of an EA. The second tier consisted of qualitatively comparing those conceptual technologies that met the definition of an EA with a must satisfy criteria. One hundred and eleven EAs (109 plus 2 added by the EASWG), including combinations of EAs, were subjected to the screening process listed in Appendix A. Two lists were generated, one listing the EAs that passed, the other listing those rejected based on not meeting the definition of an EA. The screening process is illustrated in Figure 2-2.

2.2.2.1 Screening

The screening process conducted by the EASWG is described in detail in "Engineered Alternatives Cost Benefit Study Screening Report," Appendix D. The EASWG was comprised of a professional facilitator and technical professionals from the following fields:

- Waste management
- Waste processing
- Probabilistic risk assessment
- Transportation engineering
- Environmental engineering
- Mine engineering
- Radiation risk assessment
- Chemical engineering
- Cost/schedule assessment
- Public relations.

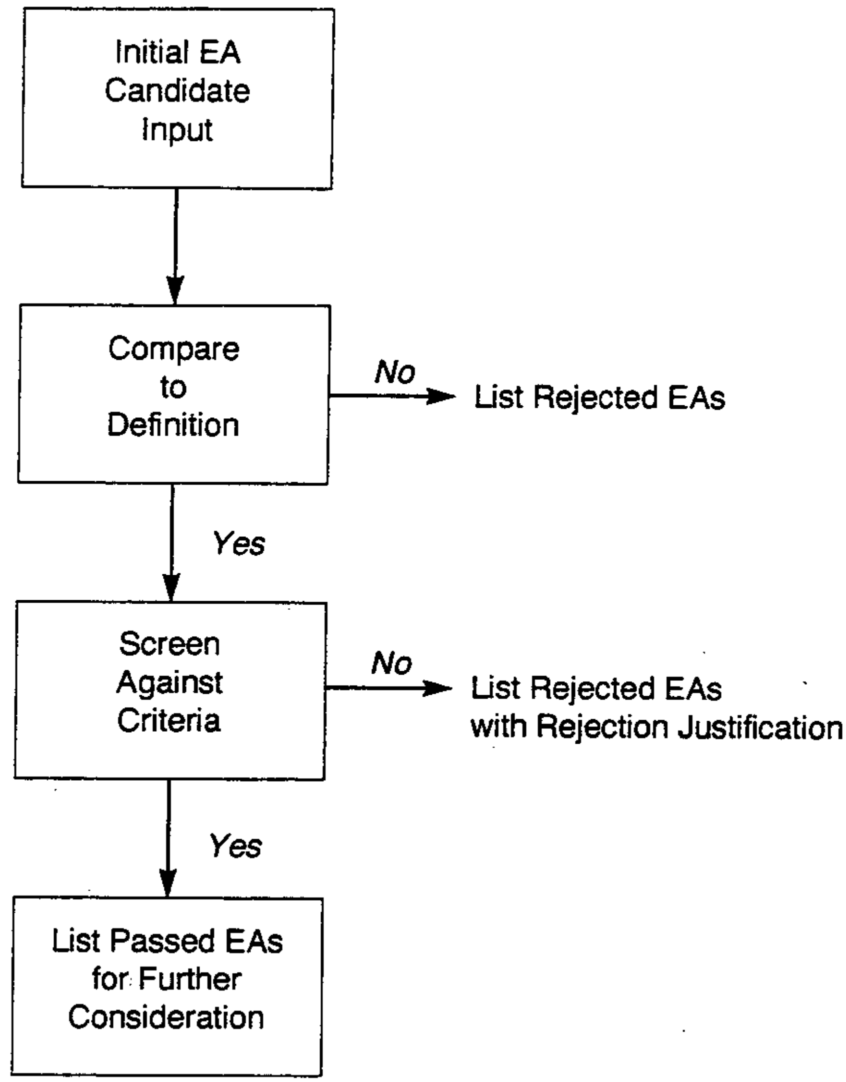

Figure 2-2
EACBS Screening Process

The individuals chosen to participate in the EASWG activities had technical experience in the fields listed and had direct knowledge of the WIPP project and/or other DOE waste management programs. Additional information regarding the details of the screening process, identification of the individuals assigned to the EASWG, and resumes of their experience can be found in Appendix D.

The EASWG met on April 24, 25, and 26, 1995 and again on May 1, 2, and 3, 1995.

From a review of the scoping report (Appendix D) the working group broke the screening process down into the following steps:

1. Review the definition of an EA.
2. Review the screening criteria.
3. Review the EA candidates and their definitions.
4. Outline the screening process.
5. Compare the EA candidates to the EA definition. Document the results.
6. Determine if the EAs that met the definition also meet the screening criteria.
7. Document the results.

The components of the EA screening process are discussed in the following sections.

2.2.2.2 Engineered Alternative General Definition

The EASWG first developed the definition of an EA for use at WIPP, this definition states:

> An EA is a technically feasible process, technology, method, repository design, or waste form modification which makes a significant positive impact on the disposal system in terms of reducing uncertainty or improving long-term performance. An EA must meet the definition of a "barrier" (engineered or man-made aspect of definition) as defined in 40 CFR 191 and the final waste form must meet the WIPP Waste Acceptance Criteria (WAC).

To meet the definition, an EA must satisfy at least one of the following conditions.

- Reduce permeability of the waste stack.
- Increase the shear strength of the waste form.
- Reduce the total gas produced from the waste form by:
  - Reducing corrosion potential or rate
  - Reducing microbial activity
  - Isolating or lowering available water/brine contact with the waste[2]
- Reduce the transport rate of radionuclides.
- Reduce the consequences of human initiated processes or events.

[2]Radiolysis gas generation is not a critical issue and is not a significant factor in gas generation (WID, 1995b).

- Reduce the solubility of the radionuclides.

2.2.2.3 Screening Criteria

The EASWG based the screening criteria on those used in the EATF. The EATF, in developing its final report (DOE, 1991a), used a process which subjected EAs to a "must satisfy" criteria consisting of three elements:

- Regulatory compliance and permitting
- Availability of technology
- Schedule of implementation.

In reviewing the criteria used previously, the EASWG concluded that the EATF criteria are based on feasibility and abbreviated two of the titles to Regulatory Feasibility and Technological Feasibility. The EASWG also noted that the scheduling criterion is inherent in each of the feasibility criteria and therefore did not consider schedule as a separate requirement.

Regulatory Feasibility requires that the technology of EAs being considered must be licensable or permittable in today's political climate. The EA or technology must have a likelihood to demonstrate regulatory compliance including local, state, or federal permits to operate. Technological Feasibility requires that the EA must have been demonstrated at a minimum of laboratory bench scale and must have the potential for full-scale implementation in the future (Appendix D). All EAs that were eventually analyzed in the EACBS contain technologies that were beyond bench scale.

2.2.2.4 Review Engineered Alternatives and their Definitions

The EASWG reviewed the EAs listed in Appendix A and made adjustments to the list, as appropriate. Some of the original titles were modified to expand on which waste types were used with the technologies. Some of the definitions were clarified or expanded to update advancements in technologies since 1991. The following summarizes these adjustments:

EA 4—Wet Oxidation

EA 4, Wet Oxidation, was divided into 4a (Wet Oxidation and Cement) and 4b (Wet Oxidation and Vitrify). Wet oxidation alone would not meet the WAC of no free liquids. Cementation and Vitrification represented two technologies for stabilizing the waste and meeting the criterion.

EA 11—Melt Metals

EA 11, Melt Metals, was divided into 11a (Melt Metals) and 11b (Melt Metals and Partition Actinides with Frit). EA 11a (Melt Metals) provides for casting the metals into ingots prior to disposal in the WIPP. EA 11b (Melt Metals and Partition Actinides with Frit) provides for adding glass frit to partition the radionuclides into slag, removing the slag for disposal at WIPP and casting the metal into ingots for disposal in an low-level waste (LLW) facility.

EA 16—Acid Digestion

EA 16, Acid Digestion, was divided into 16a (Acid Digestion and Cement) and 16b (Acid Digestion and Vitrify) for the same reasons that initiated dividing EA 4 into two separate EAs.

EA 110—Enhanced Solidification of Sludges

EA 110, Enhanced Solidification of Sludges, was developed when the EASWG recognized that cementation had been used along with other process enhancements for EAs but that no single EA employed an enhanced cementation process for sludges.

EA 111—Clay Base Backfill

EA 111, Clay Base Backfill, provides for using both swelling (i.e., bentonite) and non-swelling clays with or without other backfill additives (grout or salt).

2.2.2.5 Outline the Screening Process

The following outline was developed by the EASWG for screening EAs:

1. Compare EA to definition and determine if the EA is positive or detrimental to the disposal system.
2. Identify duplicate EAs and delete.
3. Compare remaining EAs to screening criteria
   a. Regulatory Feasibility
   b. Technological Feasibility.

This outline is illustrated in Figure 2-2.

2.2.2.6 Compare the Engineered Alternative Candidates to the EA Definition

The EASWG compared each of the EAs to the general definition of an EA. Two lists were developed based on this review. The "pass" list identified those EAs that met the definition. The "reject" list identified those EAs that did not meet the definition. The reject list documented the working group's rationale for determining why the specific EA did not met the general definition. The original reject list can be found in Appendix D. The pass list is addressed in more detail in Section 2.2.3 below.

2.2.2.7 Compare the Engineered Alternatives to the Screening Criteria

The Pass list EAs were then individually evaluated against the screening criteria defined as Regulatory Feasibility and Technological Feasibility. Some of the Pass list EAs where screened out as a result of evaluating their properties against these two criteria.

2.2.2.8 Description of Screening Output

The pass list described above is comprised of 54 total EAs. Appendix B contains a list of the EAs which passed the EA definition and screening criteria. Included in Appendix B is a brief description of individual EAs and a justification for the EASWG's assigning each EA to the pass list.

None of the EAs identified in proposed rule 40 CFR 194 (EA 100 through EA 109) were assigned to the Pass List. The justifications for rejecting these EAs were either that the individual EAs where duplicate to EAs on the Pass List or that the EA was inherent in other EAs on the Pass List. For a detailed explanation of each EA that was rejected, see Appendix C.

2.2.3 Engineered Alternatives Optimization

The EACBS began with 111 potential EAs and used the screening process described in Section 2.2.2, Screening Methods, to screen this list down to 54. The initially screened EAs were further optimized to determine the optimal set of EAs to focus upon. The optimization of EAs was needed to determine which EAs should be included in the benefit/detriment analysis based on relative potential importance.

The optimization was done with two steps. First, an optimization method was developed and EA recommendation made. The DOE-CAO then used the optimization information to identify the final list of EAs to be considered in the EACBS analysis.

2.2.3.1 Initial Optimization

A method was developed to optimize the list of 54 screened alternatives found on the pass list. This method based EA selection on alternatives that were very feasible, very effective, or combinations of these attributes. The method selected EAs that addressed all disposal system performance parameters, both singly and in combinations. The method scored the 54 EAs in technological and regulatory feasibility categories, as well as effectiveness in the four general categories of performance; gas generation, actinide solubility, waste permeability, and waste shear strength. Once the qualitative assessments were completed by the EASWG, an objective statement was made and criteria developed. Based on the criteria and relative scores, a recommendation of EAs for further analysis was made. Appendix D describes the initial optimization process in detail and presents the qualitative assessment of EA feasibility and effectiveness along with the list of 14 optimized EAs.

2.2.3.2 Second Optimization

The list of 14 EAs was reviewed by DOE-CAO and further processed into a list of nine EAs plus nine EA variations. This process took into account recent SPM analysis results concluding that gas generation, a disposal system performance parameter, is not a critical issue for the WIPP repository. This method eliminated parameters that are primarily concerned with reduction in gas generation potential and added several alternatives that will provide benefit related to actinide solubility, waste strength, and waste permeability—issues that have been found to be critical performance parameters. The salt backfill alternative #12 was removed because salt is used in improving disposal system performance and in other selected EAs as a filler material.

During the DOE-CAO review, modifications were made to the nine selected EAs. These modifications considered other backfills in the combination EAs and modified some of the original backfills. Appendix A, Table A-3 details the changes made to the original list of 14 EAs and briefly describes the modifications. The finalized list of 18 EAs used in the EACBS are referenced in Table 2-1. The results of the screening and optimization process are summarized in Figure 2-3. This figure illustrates the EAs that were selected for additional analysis after each round of evaluation.

2.2.3.3 Conclusion

Optimization of EAs initially assessed the technological and regulatory feasibility for the 54 EAs. A qualitative assessment was made on the effectiveness of each EA in addressing gas generation, actinide solubility, waste permeability, and waste strength. The EACBS chose not to include transportation and consequence of human intrusion in this assessment. The results of this assessment were used to recommend 14 initial EAs to the DOE-CAO. The DOE used the initial optimization information and recent information from the SPM and other related studies to further identify the EAs. This resulted in the 18 final EAs that were analyzed in the EACBS.

2.3 PROGRAM PARAMETERS AND GUIDING ASSUMPTIONS

The EACBS was performed using a well defined set of guiding assumptions, EA definitions, and parameter values. These values, assumptions, and definitions are discussed below.

2.3.1 Engineered Alternatives Definitions

The baseline and the 18 final EAs were evaluated by the EACBS and are described in detail in the following subsections. Table 2-2 summarizes and compares the characteristics of each of the EAs.

The 18 EAs are composed of nine basic EAs and nine variations of those basic EAs (see Table 2-1). Only the baseline and the nine basic EAs are described to preclude redundancy.

2.3.1.1 Baseline Treatment to the WIPP WAC

The baseline for managing TRU waste includes retrieving waste from earth-covered storage, characterizing the waste in accordance with the requirements of the Transuranic Waste Characterization Quality Assurance Program Plan (QAPP) (DOE, 1995d), treating and repackaging the waste only as necessary to meet the requirements of the WIPP WAC (DOE, 1991c), storing the waste, certifying that the waste meets WIPP WAC requirements, and shipping the waste to WIPP for disposal. Each of the DOE sites that stores and/or generates TRU waste will be responsible for developing the capabilities needed to characterize and ship its TRU waste. Smaller sites may send their waste to larger sites for treatment and interim storage pending shipment to WIPP.

Characterization of TRU waste packages includes:

- Nondestructive assay—Techniques used to identify and quantify radionuclides in TRU waste.

- Radiography—A nondestructive testing method that utilizes X-rays to inspect and determine the physical form of waste.

1 **TABLE 2-1**

EAS ANALYZED IN THE EACBS

ID Number	Description
#1	Supercompact Organics and Inorganics, no backfill, as received sludges.
#6	Shred and Compact Organics and Inorganics, no backfill, as received sludges.
#10	Plasma Processing of All Waste, no backfill.
#33	Sand Plus Clay Backfill, as received waste.
#35a	Salt Aggregate Grout Backfill Around Drums, as received waste.
#35b	Cementitious Grout Backfill, as received waste.
#77a	Supercompact organics and inorganics, salt aggregate/grout backfill, monolayer of 2000 drums in a 6- x 33- x 300-foot room.
#77b	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums in a 6- x 33- x 300-foot room.
#77c	Supercompact organics and inorganics, sand/clay based backfill, monolayer of 2000 drums in a 6- x 33- x 300-foot room.
#77d	Supercompact organics and inorganics, salt/CaO backfill, monolayer of 2000 drums in a 6x33x300 foot room.
#83	Salt backfill with CaO, as received waste.
#94a	Enhanced cement sludges, shred and add clay based material to organics and inorganics, no backfill.
#94b	Enhanced cement sludges, shred and add clay based material to organics and inorganics, sand/clay grout backfill.
#94c	Enhanced cement sludges, shred and add clay based material to organics and inorganics, cementitious grout backfill.
#94d	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.
#94e	Enhanced cement sludges, shred and add clay based material to organics and inorganics, clay based backfill.
#94f	Enhanced cement sludges, shred and add clay based material to organics and inorganics, CaO/Salt backfill.
#111	Clay Based Backfill, as received waste.
Baseline	Baseline disposal system design, no backfill, treatment to WIPP WAC.

Original List of Potential Engineered Alternatives

EATF-1	EATF-29	EATF-57	SPM-E
EATF-2	EATF-30	EATF-58	SPM IT-1
EATF-3	EATF-31	EATF-59	SPM IT-2
EATF-4	EATF-32	EATF-60	SPM IT-3
EATF-5	EATF-33	EATF-61	SPM IT-4
EATF-6	EATF-34	EATF-62	SPM IT-5
EATF-7	EATF-3 5	EATF-63	SPM IT-6
EATF-8	EATF-36	EATF-64	SPM IT-7
EATF-9	EATF-37	EATF-Baseline	SPM IT-8
EATF-10	EATF-38	EATF-Alt. 1	SPM IT-9
EATF-11	EATF-39	EATF-Alt. 2	SPM IT-10
EATF-12	EATF-40	EATF-Alt. 3	SPMEATF-8
EATF-13	EATF-41	EATF-Alt. 4	SPMEATF-9
EATF-14	EATF-42	EATF-Alt. 5	SPM DOE-1
EATF-15	EATF-43	EATF-Alt. 6	SPM DOE-2
EATF-16	EATF-44	EATF-Alt. 7	CFR-100
EATF-17	EATF-45	EATF-Alt. 8	CFR-101
EATF-18	EATF-46	EATF-Alt. 9	CFR-102
EATF-19	EATF-47	EATF-Alt. 10	CFR-103
EATF-20	EATF-48	EATF-Alt. 11	CFR-104
EATF-21	EATF-49	EATF-Alt. 12	CFR-105
EATF-22	EATF-50	EATF-Alt. 13	CFR-106
EATF-23	EATF-51	EATF-Alt. 14	CFR-107
EATF-24	EATF-52	SPM-Baseline	CFR-108
EATF-25	EATF-53	SPM-A	CFR-109
EATF-26	EATF-54	SPM-B	EASWG-110*
EATF-27	EATF-55	SPM-C	EASWG-111*
EATF-28	EATF-56	SPM-D	

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Potential Engineered Alternatives After First Round of Screening

EATF-1	EATF-63
EATF-2	EATF-64
EATF-3	EATF-Alt. 1
EATF-4a	EATF-Alt. 2
EATF-4b	EATF-Alt. 3
EATF-5	EATF-Alt. 4
EATF-6	EATF-Alt. 5
EATF-7	EATF-Alt. 6
EATF-8	EATF-Alt. 7
EATF-9	EATF-Alt. 8
EATF-10	EATF-Alt. 9
EATF-11a	EATF-Alt. 10
EATF-11b	EATF-Alt. 11
EATF-12	EATF-Alt. 12
EATF-15	EATF-Alt. 13
EATF-16a	EATF-Alt. 14
EATF-16b	SPM-C
EATF-19	SPM IT-2
EATF-22	SPM IT-3
EATF-29	SPM IT-4
EATF-33	SPM IT-5
EATF-35	SPM IT-7
EATF-36	SPM IT-8
EATF-38	SPM IT-9
EATF-51	SPM IT-10
EATF-53	EASWG-110
EATF-60	EASWG-111

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Potential Engineered Alternatives First Optimized List

EATF-10
EATF-12
EATF-33
EATF-35
EATF-53
EATF-60
EATF-63
EATF-Alt. 9
EATF-Alt. 10
SPM-C
SPM IT-4
SPM IT-9
SPM-IT-10
EASWG-110

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Final List of Engineered Alternatives for the EACBS Analysis

EATF-1
EATF-6
EATF-10
EATF-33
EATF-35a
EATF-35b
EATF-Alt. 12a
EATF-Alt. 12b
EATF-Alt. 12c
EATF-Alt. 12d
SPM-C
SPM IT-9a
SPM IT-9b
SPM IT-9c
SPM IT-9d
SPM IT-9e
SPM IT-9f
EASWG-111

EATF = Engineered Alternative Task Force
CFR = Code of Federal Regulations
SPM = System Prioritization Method
EASWG = Engineered Alternatives Study Working Group
* = Added by the EASWG

Stake holder inputs not included, however all stateholder EAs were duplicates of those listed in this table. For additional detail see Section 2.2.1

Figure 2-3
Summary of Engineering Alternative screening Process Results

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DOE/WIPP 95-2135 10/13/95

TABLE 2-2

SUMMARY OF ENGINEERED ALTERNATIVES EVALUATED BY EACBS RELATIVE TO THE BASELINE

Identifier	Alternative	Sludges	Solid Organic	Solid Inorganic	Backfill	Facility Design
0	Baseline	As received	As received	As received	None	Baseline
1	Supercompact waste	As received	Supercompacted	Supercompacted	None	Baseline
6	Shred and compact	As received	Shred and Compact	Shred and Compact	None	Baseline
10	Plasma processing of all waste	Plasma Processed	Plasma Processed	Plasma Processed	None	Baseline
33	Sand plus clay backfill	As received	As received	As received	Sand Plus Clay Backfill	Baseline
35.a	Salt aggregate grout backfill	As received	As received	As received	Salt Aggregate Grout Backfill	Baseline
35.b	Cementitious grout backfill	As received	As received	As received	Cementitious Grout Backfill	Baseline
77.a	Supercompact organics and inorganics, salt aggregate grout backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Salt Aggregate Grout Backfill	6X33X300
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Clay based backfill	6X33X300
77.c	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Sand/clay backfill	6X33X300
77.d	Supercompact organics and inorganics, salt plus CaO backfill monolayer of 2000 drums	As received	Supercompact	Supercompact	Salt plus CaO Backfill	6X33X300
83	Salt backfill with CaO	As received	As received	As received	Salt plus CaO Backfill	Baseline
94.a	Enhanced cement sludges, shred and cement organics and inorganics, no backfill	Enhanced Cement	Shred and add clay	Shred and add clay	No backfill	Baseline

TABLE 2-2 (Concluded)

SUMMARY OF ENGINEERED ALTERNATIVES EVALUATED BY EACBS RELATIVE TO THE BASELINE

Identifier	Alternative	Sludges	Solid Organic	Solid Inorganic	Backfill	Facility Design
94.b	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Clay/sand backfill	Baseline
94.c	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Cementitious Grout	Baseline
94.d	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Salt Aggregate Grout	Baseline
94.e	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Clay	Baseline
94.f	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Salt plus CaO Backfill	Baseline
111	Clay Based Backfill	As received	As received	As received	Clay Based Backfill	Baseline

- Sampling and analysis of headspace gas—the collection and analysis of samples of headspace gas. Headspace gas will be analyzed to determine the quantities of hydrogen, methane, and listed volatile organic compounds (VOCs) in the gas.

- Sampling and analysis of homogenous solids and soil/gravel—the collection and analysis of representative samples of waste materials classified as homogenous solids and soil/gravel. The samples will be analyzed to quantify the amounts of VOCs, semi-volatile organic compounds (SVOCs) and metals in the samples.

- Visual examination—as a quality control check on radiography, a statistically selected portion of the waste containers must be opened and visually examined.

The WIPP WAC sets limits on the amounts of free liquids, particulates, and pyrophoric materials (pyrophoric radionuclides) that are acceptable in TRU waste packages, and identifies items that are prohibited from being in TRU waste packages, including explosives and compressed gasses. If waste packages contain items that do not meet the WIPP WAC, as determined by radiographic examination, then the waste packages will be opened and the nonconforming items will be removed and treated such that they will meet the WIPP WAC requirements (e.g., liquids will be solidified, particulates will be stabilized, and compressed gas containers will be punctured). Treatment and repackaging will only be done to the extent required to meet the requirements of the WIPP WAC. For this study, it was assumed that all newly generated sludges will be cemented, and that some of the stored sludges will require re-cementing to meet WIPP WAC requirements. Wastes will be stored and managed in accordance with site-specific requirements.

2.3.1.2 Alternatives #1 and #77—Supercompact Solid Organic and Solid Inorganic Wastes

For this study, the supercompaction process is modeled after the Supercompaction and Repackaging Facility (SARF) which is in operation at the Rocky Flats Environmental Technology Site (RFETS) (DOE, 1995c). The SARF is the only supercompaction facility in the United States specifically designed to treat TRU waste. Only solid organic and solid inorganic wastes are suitable for supercompaction. In this alternative, sludges will be solidified as in the baseline according to existing procedures to meet WIPP WAC requirements.

In the SARF process, waste is first emptied into a glovebox where it is sorted to remove items which cannot be supercompacted (e.g., unpunctured aerosol cans). The incompatible items will be either treated such that they can be supercompacted (e.g., puncturing the aerosol can), or packaged such that they meet WIPP WAC requirements and sent to WIPP for disposal without supercompaction. Items suitable for supercompaction are then compacted into a 35-gallon (132-liter) drum using a low-force (30 metric ton) compactor. The compacted 35-gallon (132-liter) drums are then transferred to the supercompactor. The supercompactor applies a high force (1,500 to 2,000 metric tons) to the 35-gallon (132-liter) drum to compact the waste material into a smaller volume. The compacted drum, called a "puck," is then transferred to a 55-gallon (208-liter) drum for final packaging to WIPP WAC requirements. On average, 4 pucks can be packaged into each 55-gallon (208-liter) drum. The volume reduction ratio for supercompaction is assumed to be 2.9:1. The final waste density is assumed to be 104.8 pounds (lb) (47.5 kg)/per cubic feet (ft^3), compared to an initial density of approximately 33.3 lb (15.1 kg)/ft^3. Density is increased over that resulting simply from the volume reduction ratio because of the additional metal from the compacted drums.

With the exception of adding supercompaction, all of the other elements of the baseline are part of this alternative, including waste retrieval, waste characterization, waste storage, waste certification, and transportation. The waste placed in the repository will be load managed such that the radionuclide inventory per panel will be identical to the baseline.

2.3.1.3 Alternative #6—Shred & Compact Solid Organic and Solid Inorganic Wastes

For this study, the shred & compaction process is modeled after commercially available techniques that have been successfully used for low-level waste and TRU waste (Moghissi et al., 1986; Owens, 1995). Only solid organic and solid inorganic wastes are suitable for shred and compaction. In this alternative, sludges will be solidified as in the baseline according to existing procedures to meet WIPP WAC requirements.

The initial waste processing step is size reduction, using a shredder, such that no individual waste item has a dimension greater than 4 inches. The shredded waste is then compacted into a 55-gallon (208-liter) drum using a low-force (30 metric ton) compactor. This process is repeated, adding more waste to the drum and compacting it, until the drum is full. Once the drum is full, a lid is installed and the drum is sent to storage. The volume reduction ratio for shred and compaction is assumed to be 1.3 : 1. The final waste density is assumed to be 48.3 lb (21.9 kg)/ft^3, compared to an initial density of approximately 33.3 lb (15.1 kg)/ft^3.

With the exception of shredding and compacting waste, all of the other elements of the baseline are maintained in this alternative, including waste retrieval, waste characterization, waste storage, waste certification, and transportation. The waste placed in the repository will be load managed such that the radionuclide inventory per panel will be the same as the baseline.

2.3.1.4 Alternative #10—Treat All Wastes in Plasma Melter

For this study, the plasma melting process is modeled after the Plasma Arc Centrifugal Treatment (PACT) system that has been developed by Retech, Inc., and will be used by Lockheed Martin Environmental Systems and Technologies Co. (LESAT) as part of the Pit 9 Comprehensive Demonstration (LESAT, 1995) at the Idaho National Engineering Laboratory (INEL). This treatment technology is applicable to all waste types, and to achieve optimum operations, it is desirable to process sludges, solid organic, and solid inorganic wastes simultaneously (Nielsen, 1995).

The first step in the plasma melter system is size reduction of the waste using a shredder, such that no individual waste item has a dimension greater than 4 inches. A magnetic separator then removes most of the iron and steel from the shredded waste so that the amount of iron in the final waste form can be controlled to be less than 30 weight percent. This control is important to assure a uniform final waste form. Shredded waste will then be transferred to 55-gallon (208-liter) drums and stored temporarily until it is sent to the PACT system for treatment. The iron and steel that was separated from the waste will also be packaged in 55-gallon (208-liter) drums and stored until it is sent to the PACT system for treatment.

The PACT process is a thermal process that treats waste materials using a rotating crucible into which waste material is introduced for treatment. Treatment of the material will be accomplished with the use of a transferred arc plasma torch operating in an oxygen-rich environment. The operation of the torch in this environment will bring the waste to a molten state, destroy any organic materials, and oxidize or immobilize any heavy metals. The molten slag will then be poured into 55-gallon (208-liter) drums and allowed to cool. Upon cooling, the final molten slag becomes a non-leachable "glass". Plasma melting results in a volume reduction ratio of approximately 3 : 1 (Nielsen, 1995), and the final waste form is assumed to have a density of 100.5 lb (45.6 kg)/ft^3 compared to an initial average density of 33.1 lb (15 kg)/ft^3.

With the exception of adding the PACT system, all of the other elements of the baseline are maintained in this alternative, including waste retrieval, waste characterization, waste storage, waste certification, and transportation.

2.3.1.5 Alternative #33—Sand Plus Clay Backfill

For this alternative the waste is treated and emplaced in the same manner as for the baseline. A backfill consisting of a mixture of medium grained sand and granulated clay is placed around the waste stack and between the drums filling the void space within the rooms. The backfill is 70% sand and 30% clay by volume. The clay is commercially available granulated kaolinite or illite. The sand and clay are prepared in a hopper or drum mixer and are pneumatically placed around the waste stack after the waste is emplaced. Because of the inefficiencies associated with pneumatically placing a dry fine to medium grained material, a void space of 50% is assumed.

The clay is added to the sand to reduce the hydraulic conductivity of the backfill and impede the flow of brine and the mobility of radionuclides.

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM, 1991) and will fill the space between the waste drums and the room walls (approximately 1.64 ft [0.5 m]). The total volume of backfill material for the entire underground is approximately 3.7 million ft^3 (104,000 m^3). The hydraulic conductivity of the sand plus clay backfill is expected to range from 6 x 10^{-7} meter per second (m/s) at 0 psi stress to 9 x 10^{-9} m/s at 2,200 psi stress.

2.3.1.6 Alternative #35a—Salt Aggregate Grout Backfill

For this alternative the waste is treated and emplaced in the same manner as for the baseline. A cementitious based grout backfill using crushed salt as the aggregate and simulated WIPP brine as the added water, is pumped around the waste stack and between the drums filling the void space within the rooms. Some inefficiencies will occur in placing the grout backfill so a void space of 80% is used.

Crushed salt and simulated WIPP brine are used in the grout in order to reduce chemical incompatibilities that occur between WIPP brine and normal Portland cement based grouts and concretes (Gulick and Wakeley, 1989). The grout mix will be based on the BCT-1F mixture from Gulick and Wakeley (1989).

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM 1991) and will fill the space between the waste drums and the room walls (approximately 1.64 ft [0.5 m]). The total volume of backfill for the entire underground is approximately 5.9 million ft^3 (166,000 m^3) (calculated by 0.8 x 7,346,352 ft^3 [208,000 m^3]). The hydraulic conductivity of the salt aggregate grout backfill is assumed to be constant throughout the range of expected stresses at 1.3 x 10^{-12} m/s.

2.3.1.7 Alternative #35b—Cementitious Grout Backfill

For this alternative the waste is treated and emplaced in the same manner as for the baseline. A cementitious grout backfill using ordinary Portland cement, sand aggregate, and fresh water, is pumped around the waste stack and between the drums filling the void space within the rooms. Some inefficiencies will occur in placing the grout backfill so a void space of 80% is assumed.

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM, 1991) and will fill the space between the waste drums and the room walls (approximately 1.64 ft [0.5 m]). The total volume of backfill for the entire underground is approximately 5.9 million ft^3 (166,000 m^3). The hydraulic conductivity of the cementitious grout backfill is assumed to be constant throughout the range of expected stresses at 1.3 x 10^{-12} m/s.

2.3.1.8 Alternative #83—CaO and Crushed Salt Backfill

For this alternative the waste is treated and emplaced in the same manner as for the baseline. A backfill consisting of commercially available granulated CaO (quick lime) and crushed salt aggregate is pneumatically placed around the waste stack and between the drums filling the void space within the rooms. The mixture consists of less than 10% CaO and 90% crushed salt aggregate. Because of the inefficiencies associated with pneumatically placing a dry material, a void space of 50% is assumed.

The lime is added to increase the pH of the brines in the repository environment and lower radionuclide solubility. At a pH of approximately 8.5 (30 grams CaO/liter of brine) the solubility and mobility of the radionuclides decreases significantly. Higher concentrations of CaO (higher than approximately 10%) will raise the pH of the brine above the optimum range (a pH of 10.0) at which point the solubility and mobility of the radionuclides begins to increase.

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM, 1991) and will fill the space between the waste drums and the room walls (approximately 0.5 m). The total volume of backfill for the entire underground is approximately 3.7 million ft^3 (104,000 m^3). The hydraulic conductivity of the CaO and crushed salt backfill is assumed to range from 7 x 10^{-2} m/s at 0 pound per square inch (psi) stress to 1 x 10^{-11} m/s at 2,200 psi stress.

2.3.1.9 Alternative #94—Enhanced Cementation of Sludges, Shred and Add Clay to Solid Organic and Solid Inorganic Wastes

This alternative includes two treatment techniques: (1) sludges will be solidified with engineered cement to improve performance as a waste form, and (2) the solid organic and solid inorganic wastes will be shredded and clay will be added to reduce the void space in the final waste form. For the purposes of this study, the enhanced cementation process will be modeled after existing facilities that solidify radioactive sludge wastes. No facility in the United States is known to shred waste and add clay before storage and/or disposal. However, the required technologies are commonly used in industry and it is anticipated that this treatment system could be developed with little difficulty. For this study, the shred/add clay process will be modeled after facilities that shred and add cement-based grout to waste. The required equipment should be similar to that now used by shred/add grout and shred/add clay facilities, and the operating costs will be adjusted to account for the difference in materials costs between grout and clay.

The first step in the enhanced cementation process is size reduction of sludges that were previously solidified. Size reduction will be accomplished using a standard industrial crusher/shredder. The crushed waste will then be placed into transfer containers and loaded into a feed hopper. The waste will then be fed from the hopper and mixed with enhanced cement and placed into 55-gallon (208-liter) drums. Newly generated sludges would not be processed for size reduction but would go directly to the feed hopper, similar to the method currently being use to solidify sludges. The exact formula for the enhanced cement has not been determined, but possibilities include sulphur-polymer cement, portland cement with additives, and portland cement mixed with fiberglass. This process has a volume increase ratio of 2.5:1. The density of the final waste form is assumed to be 40.8 lb (18.5 kg)/ft^3 compared to an initial density of 32.3 lb (14.6 kg)/ft^3.

The first step for the shred/add clay process, is size reduction of the incoming waste stream using a shredder, such that no individual waste item has a dimension greater than 4 inches. The shredded waste will then be placed into transfer containers and loaded into a feed hopper. The waste will then be fed from the hopper and mixed with clay (e.g., kaolin) pellets and placed into 55-gallon (208-liter) drums. It is assumed that the clay will fill 80% of the initial void volume in the waste package. The final density of the waste is assumed to be 78.5 lb (35.6 kg)/ft^3 compared to an initial average density of 33.3 lb (15.1 kg)/ft^3. There is also assumed to be no net change to the waste volume (i.e., treatment of one drum of waste results in one drum of treated waste).

With the exception of adding the enhanced cementation and shred/add clay waste processing steps, all of the other elements of the baseline are maintained in this alternative, including waste retrieval, waste characterization, waste storage, waste certification, and transportation.

2.3.1.10 Alternative #111—Clay Based Backfill

For this alternative, waste is treated and emplaced in the same manner as for the baseline. A backfill consisting of commercially available pelletized kaolinite or illite clay (DOE, 1995a) is place pneumatically around the waste stack and between the drums filling the void space within the rooms. Pelletized clay is used to reduce potential dust inhalation safety issues. Because of the inefficiencies associated with pneumatically placing a dry material, a void space of 50% is assumed.

The clay is used to reduce the hydraulic conductivity of the backfill and impede the flow of brine and the mobility of radionuclides.

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM, 1991). The total volume of backfill for the entire underground is approximately 3.7 million ft^3 (104,000 m^3). The hydraulic conductivity of the clay based backfill is assumed to range from 1 x 10^{-10} m/s at 0 psi stress to 2 x 10^{-13} m/s at 2,200 psi stress.

2.3.2 Program Assumptions

Throughout the analysis of EAs many assumptions were made relative to waste inventory, waste processing, and waste characteristics. Assumptions were used in the basic program approach, the screening process and the actual analysis within the factors. Many of these assumptions are specific to the screening process or factor and are described in the respective screening and analysis factor sections (see Chapter 3.0). The following describes the common guiding assumptions used throughout the EACBS.

- The baseline repository design is in compliance with 40 CFR 191. EAs evaluated in this study will be used to provide additional assurance for a disposal system that is compliant with the containment requirements.

- The analysis is a tool to assess cost and benefit of EAs, not to recommend or rank alternatives. Weighting of factors was not performed as part of this study.

- The output of the EACBS will provide the DOE with information that will allow for the selection or rejection of an EA if additional engineered barriers are desirable.

- For waste processing EAs that increase the actinide concentration in the waste (i.e., volume reduction EAs), rooms and panels will be load managed to maintain the baseline actinide inventories for each room and panel. The waste containers are assumed to be evenly distributed throughout the rooms and panels.

- Schedule analysis was performed to determine the outer bound impact. Emplacement of waste would start only after processing/treatment facilities were on-line. No waste was assumed to be emplaced prior to this date even if the EA did not process all of the waste (i.e., sludges could be emplaced prior to the startup of a shred and grout facility). The baseline, however, did assume waste would be emplaced prior to completion of WIPP WAC treatment facilities. The baseline analysis reports the date processing facilities are on-line, however waste would be emplaced prior to this date.

- All waste processing EAs are performed on 100% of the affected wastes. No EA is assumed to be performed on a percentage of the waste available for processing by the EA. This represents the upper end impacts with the baseline being the lower end. Any variation in the processed waste percentage would fall between these bounds.

- The operational period is assumed to be at least 35 years. The waste processing facilities are assumed to operate for 20 years. These operational periods were assumed because most processing EAs have a nine year startup cycle. This assumes a startup and 20 year processing operation followed by decommissioning could be completed within a 35 year time frame.

- For the EACBS, the waste volume is assumed to be 6.2 million (M) ft^3 (0.175 M m^3). If an EA reduces the waste volume, only 6.2 M ft^3 (0.175 M m^3) of waste will be treated, not the amount that would produce 6.2 M ft^3 (0.175 M m^3) of treated waste. For EAs that increase the waste volume after treatment, only

6.2 M ft^3 (0.175 M m^3) of treated waste will be emplaced, the amount of waste generated in excess of 6.2 M ft^3 (0.175 M m^3) would not be emplaced.

- The reduction of the probability of human intrusion is not considered in the EACBS. Only the consequences of an intrusion event were analyzed. No EA was considered that may reduce the probability of human intrusion, since that type of assurance measure is being considered in passive marker studies.

2.3.3 Alternative Waste Processing Configurations

In addition to the screened EAs, three waste processing site configurations were analyzed. These configurations, called decentralized, regionalized, and centralized, are based on the Draft Environmental Management Programmatic Environmental Impact Statement (EM-PEIS) analysis, and vary by the number of installations at which the selected waste processing facilities would be located. Generally, those installations which have the largest volumes of waste were selected as the locations for treatment of waste under the decentralized and regionalized alternatives. Table 2-3 summarizes the site waste transfers for each of these configurations. RH-TRU waste was only analyzed for the decentralized case.

As shown in Figures 2-4 and 2-5, the decentralized configuration evaluated characterizing and packaging TRU waste at all sites where TRU waste is generated, and shipping CH-TRU waste from the sites with smaller amounts to the nearest of the 10 sites with the largest amounts of TRU waste for treatment and interim storage prior to shipping to WIPP. The RH-TRU waste will be stored at six sites.

As shown in Figure 2-6, the regionalized configuration analyzes the impacts of consolidating CH-TRU waste at the five sites with the largest inventories of waste, and treating the waste in accordance with the various engineered alternatives at these five sites prior to shipping to WIPP.

In the centralized configuration, CH-TRU waste is characterized and packaged at all generating sites and shipped to WIPP for treatment and disposal, as shown in Figure 2-7.

2.3.4 Baseline Definition

The baseline condition is defined as the current design and disposal scheme for the WIPP. The baseline disposal system is described in Section 1.2.1 of this report and the current Final Safety Analysis Report for the WIPP (DOE, 1991b). The baseline includes multiple barriers, both natural and engineered, that isolate the waste from the accessible environment and provide confidence that the performance predictions associated with the containment requirements of 40 CFR 191.13 are met.

2.3.4.1 Baseline Parameters

The WIPP baseline conditions important to the EACBS are:

- The WIPP capacity is 6.2 million ft^3 by volume. The baseline volumes of sludges, organics, and inorganics are projected from current waste inventories.

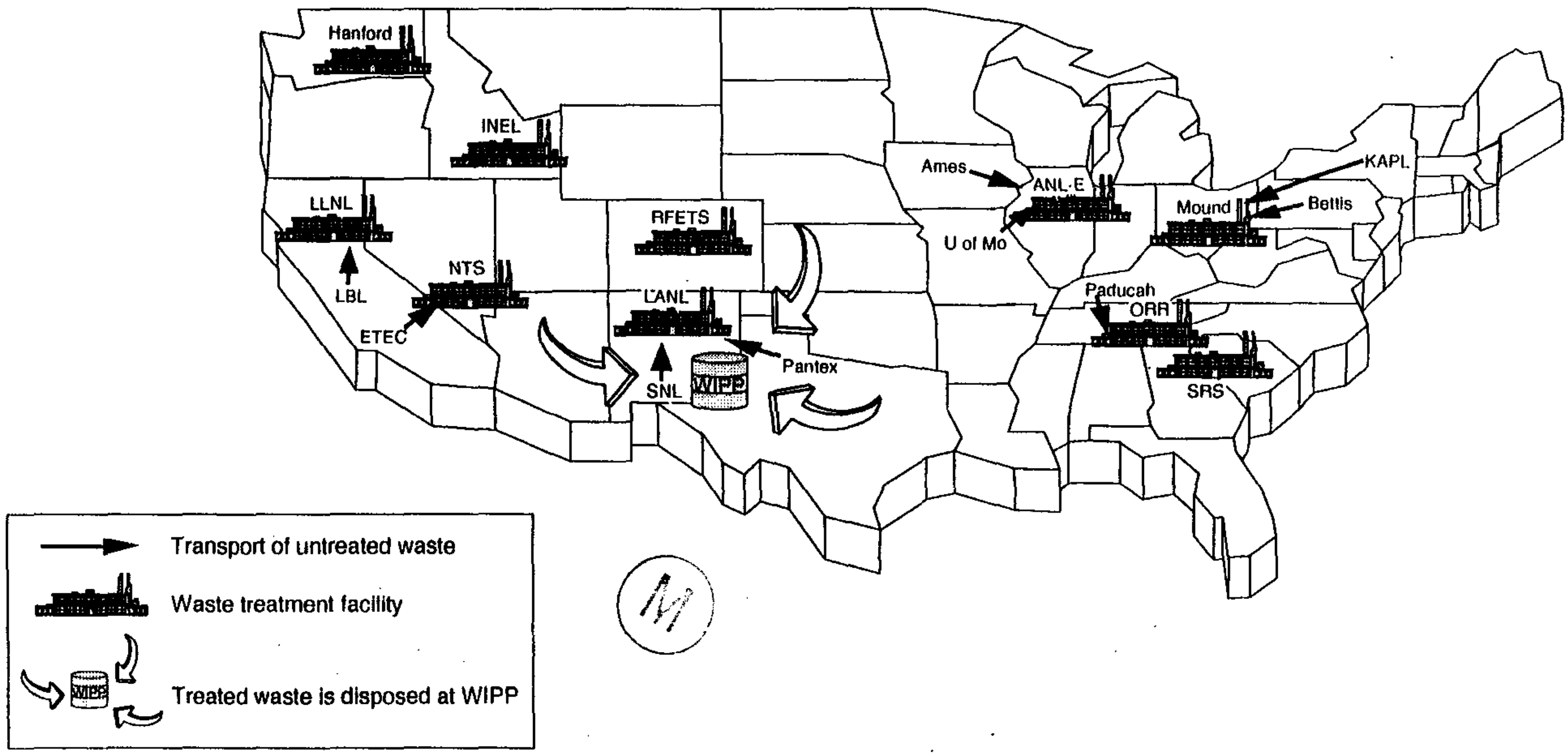
- No waste processing is required beyond that to meet the WAC.

1 **TABLE 2-3**

WIPP ENGINEERED ALTERNATIVES
SITE WASTE TRANSFERS

	Decentralized			
SITE	CH	RH	Regionalized	Centralized
ANL-E	WIPP		SRS	WIPP
Ames	ANL-E		SRS	WIPP
Battelle Columbus		ORR		WIPP
Bettis	Mound	ORR	SRS	WIPP
ETEC	NTS		INEL	WIPP
Hanford	WIPP	WIPP	WIPP	WIPP
INEL	WIPP	WIPP	WIPP	WIPP
KAPL	Mound	ORR	SRS	WIPP
LANL	WIPP	WIPP	WIPP	WIPP
LBL	LLNL		Hanford	WIPP
LLNL	WIPP		Hanford	WIPP
Mound	WIPP		SRS	WIPP
U. of Mo.	ANL-E		SRS	WIPP
NTS	WIPP		INEL	WIPP
ORR	WIPP	WIPP	SRS	WIPP
Paducah	ORR		SRS	WIPP
Pantex	LANL		LANL	WIPP
RFETS	WIPP		WIPP	WIPP
SNL/NM	LANL		LANL	WIPP
SRS	WIPP	WIPP	WIPP	WIPP

763435.01.00.00/zc A30



G95\EEC\Decent-1870.ppt

Figure 2-4

Decentralized Configuration for Contact-Handled Transuranic Waste Treatment

8/19/95

763435.01.00.00.00/zc A31

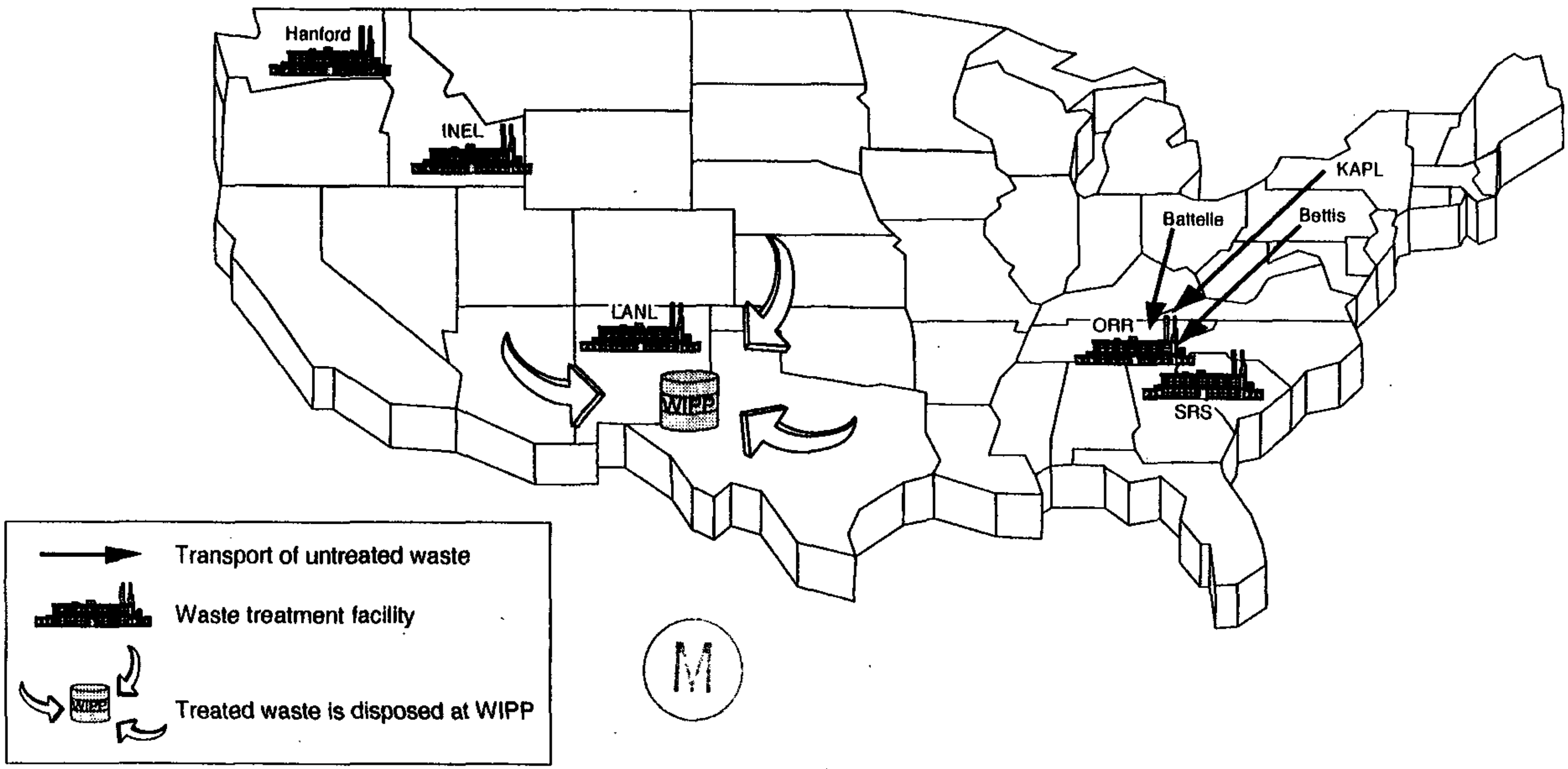


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Figure 2-5
Decentralized Configuration for Remote-Handled Transuranic Waste Treatment

8/19/95

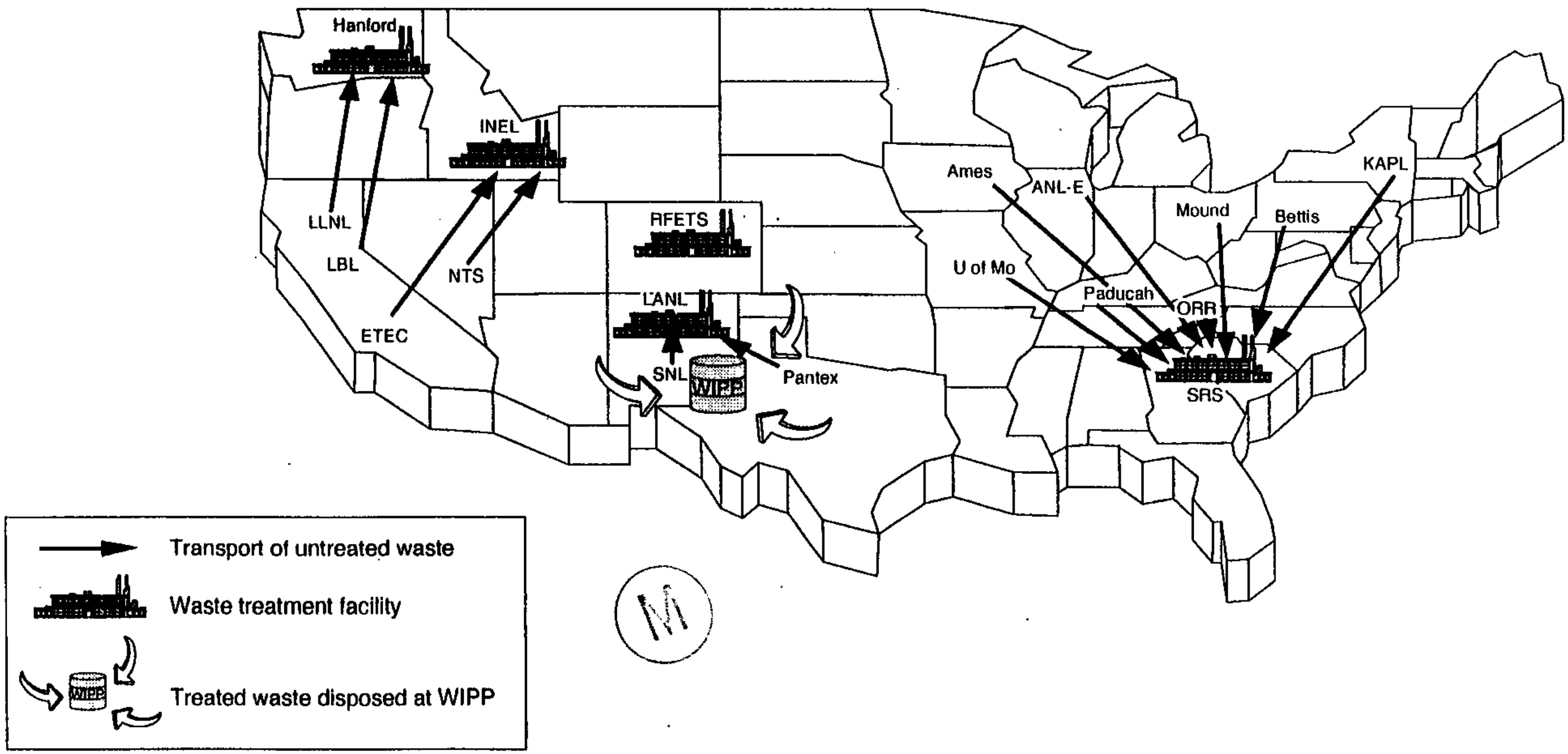

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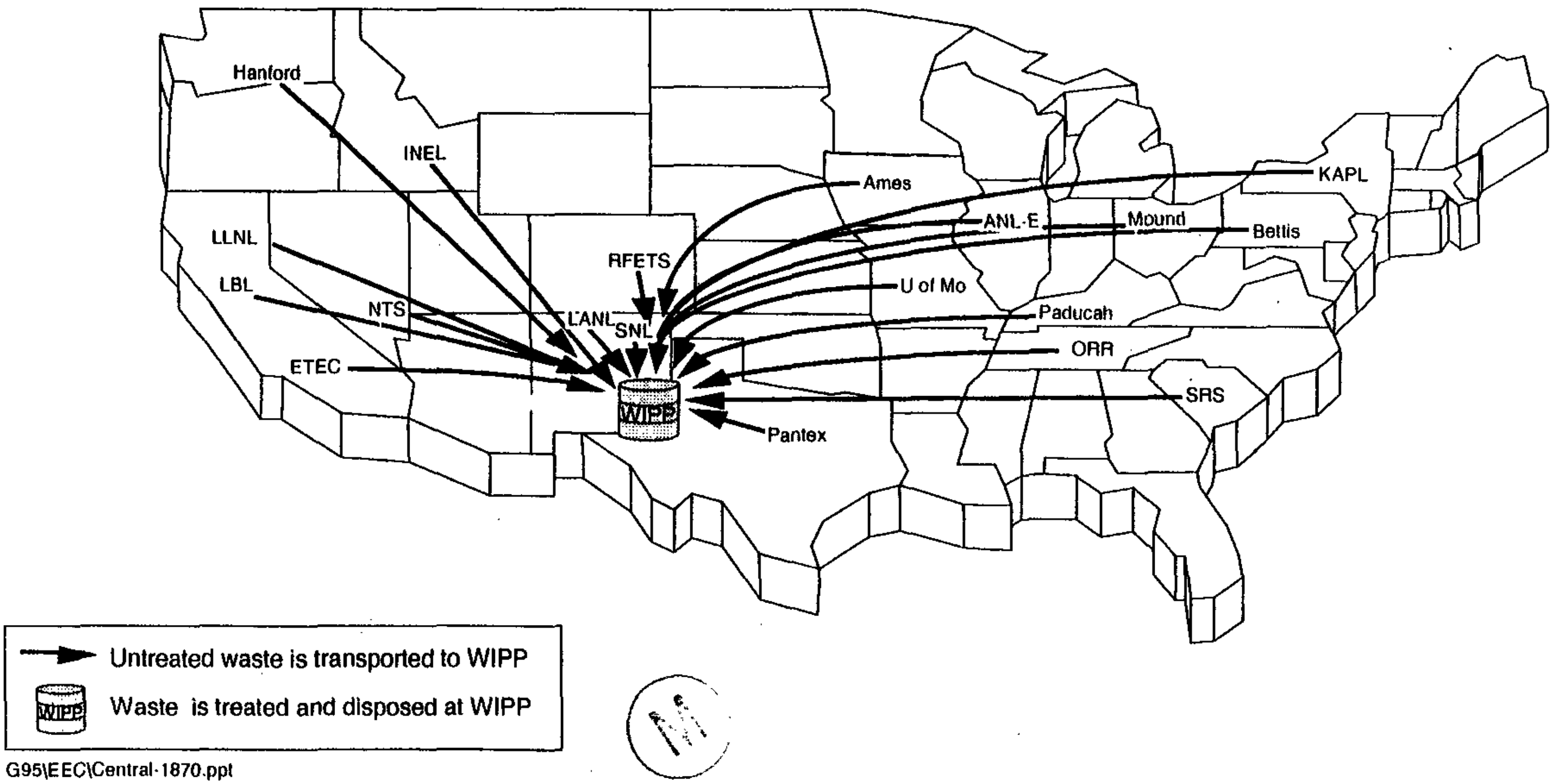
Figure 2-6
Regionalized Configuration for Contact-Handled Transuranic Waste Treatment



G95\EEC\Central-1870.ppt

Figure 2-7

Centralized Configuration for Contact-Handled Transuranic Waste Treatment

- The WIPP will be ready to accept waste in 1998.

- No backfill is used in waste disposal areas.

The baseline for waste management is assumed to be decentralized. Processing and packaging of TRU waste to meet the WAC are performed at all 16 DOE sites where these wastes are currently stored or generated. Following processing and packaging, the waste would be shipped from sites with small amounts of waste to the 10 DOE sites with the largest amount of waste for interim storage. This strategy approximates the current DOE TRU waste management policy. The 10 major DOE waste sites are listed in Table 2-4.

TABLE 2-4

TEN MAJOR DOE WASTE GENERATOR/STORAGE SITES

1	Argonne National Laboratory-East (ANL-E)
2	Hanford Site
3	Idaho National Engineering Laboratory (INEL)
4	Lawrence Livermore National Laboratory (LLNL)
5	Los Alamos National Laboratory (LANL)
6	Mound Plant
7	Nevada Test Site (NTS)
8	Oak Ridge Reservation (ORR)
9	Rocky Flats Environmental Technology Site (RFETS)
10	Savannah River Site (SRS)

For waste to meet the WIPP WAC in the baseline, aqueous liquids must be stabilized and small particulates immobilized. Organic liquids will be stabilized by organic stabilization (use of a binding agent, such as calcium silicates, to form a solid). Solid process residue will be sorted for non-compliant items, corrosive and reactive materials will be neutralized and deactivated. Noncompliant particulates will be immobilized by solidification (i.e., cement). Sludges will be sorted and repackaged if they exceed wattage limits. Soils will be grouted if particulates exceed the WIPP WAC limits.

2.3.4.2 Common Analysis Parameters

There are many common parameters used throughout the analysis, such as waste inventories, masses, densities and forms for each EA, backfill volumes, emplacement geometries and physical properties, radionuclide inventories, waste emplacement work-off schedules, waste processing rates, and number of shipments and mileage for CH-TRU and RH-TRU waste. This information is shown in Tables 2-5 through 2-10, respectively.

TABLE 2-5

SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Total Backfill (m^3)	Excavated Area Volume (m^3)	Salt Volume (m^3)	No. of Panels
0	Baseline	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	0	207,406	289,814	10
1	Compact Waste	54,389	26,019	13,438	93,846	9,385	45,097	93,846	0	0	207,406	363,092	10
6	Shred and Compact	54,389	56,498	29,181	140,068	14,007	67,308	140,068	0	0	207,406	316,870	10
10	Plasma Processing of All Waste	10,767	24,532	12,671	47,970	4,797	23,051	47,970	0	0	207,406	408,968	10
33	Sand Plus Clay Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	103,703	207,406	82,408	10
35.a	Salt Aggregate Grout Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	165,925	207,406	82,408	10
35.b	Cementitious Grout Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	165,925	207,406	82,408	10
77.a	Supercompact organics and inorganics, salt-aggregate grout backfill, monolayer of 2,000 drums, in 6- x 33- x 300-ft rooms	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	93,604	117,006	41,697	10
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2,000 drums, in 6- x 33- x 300-ft rooms	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	58,503	117,006	41,697	10

Refer to footnotes at end of table.

TABLE 2-5 (Continued)

SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Total Backfill (m^3)	Excavated Area Volume (m^3)	Salt Volume (m^3)	No. of Panels
77.c	Supercompact organics and inorganics, sand plus clay-based backfill, monolayer of 2,000 drums, in 6- x 33- x 300-ft rooms	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	58,503	117,006	41,697	10
77.d	Supercompact organics and inorganics, CaO based backfill, monolayer of 2,000 drums, in 6- x 33- x 300-ft rooms	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	58,503	117,006	41,697	10
83	Salt Backfill with CaO	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	103,703	207,406	82,408	10
94.a	Enhanced cement sludges, shred and add clay to organics and inorganics, no backfill	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	0	0	289,814	10
94.b	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, sand plus clay backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	103,703	207,406	82,408	10

Refer to footnotes at end of table.

TABLE 2-5 (Continued)

SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Total Backfill (m^3)	Excavated Area Volume (m^3)	Salt Volume (m^3)	No. of Panels
94.c	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, cementitious grout backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	165,925	207,406	82,408	10
94.d	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, salt aggregate grout backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	165,925	207,406	82,408	10
94.e	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, clay backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	103,703	207,406	82,408	10
94.f	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, CaO backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	103,703	207,406	82,408	10
111	Clay Based Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	103,703	207,406	82,408	10

Refer to footnotes at end of table.

TABLE 2-5 (Concluded)

SUMMARY OF WASTE INVENTORIES

*Unaccepted Waste Volume is the volume of CH-TRU waste that will not fit in the WIPP underground with the present panel configuration and assumptions.

Assumptions:

- Backfill filling efficiency is assumed to be 80% for fluid backfill materials and 50% for dry backfill materials
- The allowable volume of waste per panel is 16,712 cubic meters
- There are 12.54 room equivalents per panel
- Available backfill volume per panel is 732,446 ft^3 = 20,741 m^3
- The backfill height for the 77 series alternatives is assumed to be ≈0.6 m over the top of the waste and the waste is ≈0.9 m high for a total height of 1.467 m (SNL SAND91-0893/3, page 3–13)
- The total available backfill volume per panel for 77 series alternatives is = 11,701 m^3
- The volume of a waste drum is 7.35 ft^3 = 0.21 m^3.

Source: DOE, 1995e (see Appendix O for additional details).

TABLE 2-6

WIPP ENGINEERED ALTERNATIVES MASS AND VOLUME OUTPUT

	Sludges			Solid Organics			Solid Inorganics		
Case #	Total Mass (kg)	*Total Volume* (m^3)	*Density* (kg/m^3)	*Total Mass* (kg)	Total *Volume* (m^3)	*Density* (kg/m^3)	*Total Mass* (kg)	Total *Volume* (cu.m)	*Density* (kg/cu.m)
Baseline	30,921,720	54,389	569	47,234,933	74,339	635	13,007,073	38,396	339
Alternative 1	30,921,720	54,389	569	51,958,427	26,019	1,997	14,307,781	13,438	1,065
Alternative 6	30,921,720	54,389	569	51,958,427	56,498	920	14,307.781	29,181	490
Alternative 10	16,929,945	10,767	1,572	47,234,933	24,532	1,925	13,007,073	12,671	1,027
Alternative 94	53,329,327	81,566	654	111,139,691	74,339	1,495	30,604,513	38,396	797

Source: DOE, 1995e (see Appendix O for additional details).

1 **TABLE 2-7**

BACKFILL PROPERTIES FOR ENGINEERED ALTERNATIVES

Backfill Material (Alternatives Used)	Initial Density (kg/m^3)	Initial Porosity (%)	Solid[a] Density (kg/m^3)
70% Sand Plus 30% Clay (Alt. 33, 77c, 94b)	1,590[b]	40.0[b]	2,650[c]
Salt Aggregate Grout (Alt. 35a, 77a, 94d)	1,884[d]	31.3[d]	2,741[c]
Cementitious Grout (Alt. 35b, 94c)	1,884[d]	31.3[d]	2,741[c]
Clay Based (Alt. 111, 77b, 94e)	1,000[e]	62.5[f]	2,670[g]
Crushed Salt Plus CaO Backfill (Alt. 83, 77d, 94f)	1,193[h]	44.8[h]	2,162[h]

[a]Solid density is the density after consolidation to 0% porosity.
[b]Peck, R.B., W.E. Hanson, and T.H. Thornburn, 1974, *Foundation Engineering*, 2nd ed., John Wiley & Sons, New York, New York, 514 pp.
[c]Calculated from initial density and porosity.
[d]Coons, W., A. Bergstrom, P. Gnirk, M. Gray, B. Knecht, R. Pusch, J. Steadman, B. Stillborg, M. Tokonami, and M. Vaajasaari, 1987, "State-of-the-Art Report on Potentially Useful Materials for Sealing Nuclear Waste Repositories," *STRIPA Report 87-12*, prepared for the Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.
[e]Nowak, E.J., Sandia National Laboratories, 1990, Personal Communication.
[f]Calculated from initial density and solid density.
[g]Morris, D.A., and A.I. Johnson, 1967, "Summary of Hydrologic and Physical Properties of Rock and Soil Materials, as Analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948–60," *Geological Survey Water-Supply Paper 1839-D*, U.S. Government Printing Office, Washington, D.C.
[h]Case, J.B., P.C. Kelsall, and J.L. Withiam, 1987, "Laboratory Investigation of Crushed Salt Consolidation," *Proceedings of the 28th U.S. Symposium on Rock Mechanics*, June 1–July 1, 1987, Tucson, Arizona.

TABLE 2-8

WIPP ACTINIDE INVENTORY (FROM DOE, 1995e)

Nuclide	CH (Curies)	RH (Curies)	Total (Curies)
Pu-238	$1.89 \times 10^{+06}$	$3.53 \times 10^{+03}$	$1.89 \times 10^{+06}$
Pu-239	$3.85 \times 10^{+05}$	$6.41 \times 10^{+03}$	$3.91 \times 10^{+05}$
Pu-240	$7.22 \times 10^{+04}$	$1.74 \times 10^{+02}$	$7.24 \times 10^{+04}$
Pu-241	$1.01 \times 10^{+06}$	$9.06 \times 10^{+02}$	$1.01 \times 10^{+06}$
Pu-242	$1.27 \times 10^{+03}$	1.48×10^{-02}	$1.27 \times 10^{+03}$
U-233	$1.38 \times 10^{+03}$	$8.57 \times 10^{+02}$	$2.24 \times 10^{+03}$
U-235	2.88	5.66	8.54
U-238	$1.88 \times 10^{+01}$	$1.31 \times 10^{+01}$	$3.19 \times 10^{+01}$
Am-241	$2.23 \times 10^{+05}$	$5.30 \times 10^{+02}$	$2.24 \times 10^{+05}$
NP-237	$8.82 \times 10^{+01}$	1.18×10^{-02}	$8.82 \times 10^{+01}$
Th-232	6.07×10^{-01}	7.09×10^{-03}	6.14×10^{-01}
Cf-252	$1.85 \times 10^{+02}$	$5.11 \times 10^{+01}$	$2.36 \times 10^{+02}$
Totals	$3.58 \times 10^{+06}$	$1.25 \times 10^{+04}$	$3.60 \times 10^{+06}$

Source: DOE, 1995e.

1 **TABLE 2-9**

ENGINEERED ALTERNATIVES WASTE EMPLACEMENT WORK-OFF SCHEDULE FOR CH WASTE (Only EAs with Waste Processing Shown)

EA#	Processing Scenario	Number of Shipments to WIPP[1]	Number of TRUPACTS Processed/Emplaced per Day[2]
Baseline, 33, 35 (a-b), 83, 111	Decentralized	19,944	7.12
	Regionalized	19,941	7.12
	Centralized	17,401	6.21
Alternative 1	Decentralized	19,571	6.94
(Compact)[3]	Regionalized	19,548	6.93
	Centralized	17,401	8.70
Alternative 6	Decentralized	18,794	8.52
(Shred & Compact)[3]	Regionalized	18,838	8.58
	Centralized	17,401	8.70
Alternative 10	Decentralized	17,174	5.72
(Plasma) Based on 25 yr. due to 100% waste being	Regionalized	17,186	5.80
processed[3]	Centralized	17,401	8.70
Alternative #77a	Decentralized	19,571	6.99
(Super Comp, monoL	Regionalized	19,548	6.93
6-ft rm, Salt Aggreg BF)[3]	Centralized	17,401	8.70
Alternative 77b	Decentralized	19,571	6.94
(Super Comp, monoL	Regionalized	19,548	6.93
6-ft rm, Clay BF)[3]	Centralized	17,401	8.70
Alternative 77c[3]	Decentralized	19,571	6.94
(Super Comp, monoL	Regionalized	19,548	6.93
6-ft rm, Clay BF)[3]	Centralized	17,401	8.70
Alternative 77d	Decentralized	19,571	6.94
(Super Comp, monoL	Regionalized	19,548	6.93
6-ft rm, CaO BF)[3]	Centralized	17,401	8.70

1 **TABLE 2-9 (Continued)**

ENGINEERED ALTERNATIVES WASTE EMPLACEMENT WORK-OFF SCHEDULE (Only EAs with Waste Processing Shown)

EA #	Processing Scenario	Number of Shipments	Number of TRUPACTS Processed/Emplaced per Day
Alternative 94a	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, no BF)[3]	Centralized	17,401	8.70
Alternative 94b	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized	17,401	8.70
Alternative 94c	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized	17,401	8.70
Alternative 94d	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized	17,401	8.70
Alternative 94e	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized[4]	17,401	8.70
Alternative 94f	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized	17,401	8.70

[1]The number of shipments is based on the number of shipments to the WIPP only.
[2]The number of TRUPACTS is based on a 35 year operational life for WIPP.
[3]The emplacement activity is 25 years based on a 10 year lag for waste processing activities.
[4]The waste emplacement activity exceeds the 35 year operational due to 28.6 years for TRUPACT II processing.

TABLE 2-10

ENGINEERED ALTERNATIVES WASTE PROCESSING RATES

(Only EAs with Waste Processing Shown)

Alternatives	Sludges (m^3)	Solid Organics (m^3)	Solid Inorganics (m^3)
Baseline	2,719	3,717	1,920
Alternative 1	2,719	1,301	672
Alternative 6	2,719	2,825	1,459
Alternative 10	538	1,227	634
Alternative 94	4,078	3,717	1,920

3.0 FACTORS ANALYSES

Chapter 3.0 is organized by subsections as a function of the analysis of each of the eight factors listed below. These eight factors were summarized from the nine evaluation factors prescribed in the proposed rule 40 CFR 194. For consistency in analyses, Factors 1 and 9 have been combined for use in the EACBS.

1. Effects of engineered alternatives on long-term performance of the disposal system.

2. The increased or reduced uncertainty in compliance assessment

3. Impact on public and worker exposures to radiation (at the WIPP and off site) both during and after incorporation of an EA

4. The increased ease or difficulty in future removal of the waste from the WIPP disposal system

5. The increased or reduced risk of transporting the waste to the WIPP (radiation and chemical exposure, both incidental and accidental)

6. The increased or reduced public confidence in the performance of the disposal system

7. The increased or reduced total DOE waste management system cost and schedule impacts

8. The impact on other waste disposal programs from the incorporation of an EA.

3.1 FACTOR 1: EFFECTS OF ENGINEERED ALTERNATIVES ON LONG-TERM PERFORMANCE OF THE DISPOSAL SYSTEM

3.1.1 Definition of Factor 1

Factor 1 deals with the impacts that an EA is predicted to have on the long-term performance of the disposal system. Impacts are predicted using the Design Analysis Model (DAM), which considers the coupled processes of brine inflow, creep closure, gas generation, and radionuclide migration under undisturbed conditions, and also considers the consequences of three human intrusion scenarios. The three human intrusion scenarios considered by the simulation postulate the existence of future boreholes that inadvertently penetrate the waste horizon and affect the containment and isolation characteristics of the TRU waste disposal system. These scenarios are the same as those considered in the PA conducted by SNL/NM, and are fully described in SNL/NM (1993) and Appendix E. These three scenarios are referenced in the EACBS as E1, E2, and E1E2. Section 2.1 specifies that this factor also analyzes the movement of water. This is indirectly addressed within the radionuclide movement analysis because radionuclide movement is partially driven by water/brine movement. Factor 1 is evaluated by considering the impacts of each EA on the following:

- Relative changes in the release of radionuclides in drill cuttings from each of the three human intrusion scenarios

- Relative changes in the cumulative 10,000-year release of radionuclides into the overlying Rustler formation from each of the three human intrusion scenarios

The impacts of each EA are expressed as changes in the above parameters relative to the baseline, which is defined as untreated waste (except as required by the WIPP WAC) emplaced in disposal panels with no backfill.

Although both disturbed and undisturbed conditions are simulated, the study places emphasis on the effects of EAs on mitigating releases from human intrusion scenarios. Releases to the accessible environment are not predicted to occur during undisturbed performance.

The following parameters are considered as part of the Factor 1 analysis.

Porosity and Permeability of the Waste/Backfill Composite Material

The permeability of the waste/backfill composite material in the room is a major factor in controlling the flow of contaminated brine in a waste disposal room toward a human intrusion drill hole that penetrates the room. In addition, a reduction in the initial porosity or void volume of the room will result in a faster approach to lithostatic pressure, due to a reduction in the volume available for gas expansion and a reduction of the time period over which brine can flow along a pressure gradient towards the disposal rooms.

Most EAs provide a moderate to large reduction in porosity of the waste/backfill composite material. Reductions in porosity translate into reductions in permeability in a non-linear manner. Supercompaction provides only a slight decrease in permeability, whereas plasma processing of the waste or addition of clay to the backfill provides a larger decrease in permeability.

Brine Inflow Rates

Limited amounts of brine have been observed to flow into the underground excavations in response to the transient pressure gradient imposed by the excavations (Deal et al., 1989). The undisturbed units of the Salado Formation within the repository horizon contain 0.60 percent by weight (1.56 percent by volume) brine (Deal et al., 1989). This source of this brine is probably Permian seawater that became trapped in the evaporite sequence at the time of deposition. The majority of the brine observed to seep into the underground excavations is predominantly local brine that became redistributed within the disturbed rock zone (DRZ) that forms around the excavations.

Brine inflow is a process of concern because it provides a medium for the potential transport of radionuclides. Human intrusion events can create a potential pathway for the migration of contaminated brine towards the accessible environment. Brine contacting the waste is assumed to dissolve the five actinide elements of concern (plutonium [Pu], neptunium [Np], uranium [U], thorium [Th], and americium [Am]) at concentrations equal to their respective solubility limits (reference Appendix G).

Brine inflow is also a process of concern because the water will react with steel drums, standard waste boxes, and iron and aluminum waste materials, to form iron and aluminum oxides plus hydrogen gas. The two likely reactions involving iron are predicted to be (SNL/NM, 1993):

$$3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2 \quad (3.1)$$

and

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2 \quad (3.2)$$

It is important to note that water (or brine) is required for this reaction to occur, and that water (or brine) is consumed by the reaction. The reaction is thus self-limiting because, as long as there is metal in the room, any brine that flows into a room will be converted into metal oxide plus hydrogen gas. Accumulation of brine in a room will only occur if the brine inflow rate is greater than the metal corrosion rate, or if all of the metals have already been completely corroded.

Shear Strength of the Waste/Backfill Composite

One significant pathway for the release of radionuclides in response to human intrusion events is the direct removal of drill cuttings to the surface. The total volume of waste (V) that is brought to the surface in response to a drilling event is calculated by:

$$V = \pi \bullet (\text{effective radius of borehole})^2 \bullet \text{height of waste} \quad (3.3)$$

The effective radius of the borehole is equal to the actual radius of the drill bit plus any waste surrounding the borehole that might spall or erode into the borehole in response to the action of the drill bit or the circulation of drilling mud. The actual radius of the drill bit is an assumed value that is based on current oil field drilling practices. The second component of the effective radius term is controlled in part by the shear strength of the waste/backfill composite. Alternatives that increase the shear strength of the waste (such as supercompaction or plasma processing) or backfill (such as grout) will result in the removal of a smaller volume of waste to the surface in response to a drilling event, reducing the radiological consequences of the intrusion event.

Radionuclide Solubility

One pathway considered for the release of radionuclides to the accessible environment is the dissolution of the radionuclides in brine that may come in contact with the waste, followed by transport of the contaminated brine to the accessible environment. Brine can be transported via fractures caused by excessive pressurization of the repository by gas generation, or by pathways created by future inadvertent human intrusions. A key factor controlling the release of radionuclides by these mechanisms is the solubility of the radionuclides in brine. For this study, solubility is defined in this case as the maximum mass of a given actinide element that can dissolve in a unit volume of brine of a specified composition. The solubilities of the relevant actinide elements are complex functions of several parameters, however, they all show similar behavior with respect to pH, showing a decrease in solubility as the pH is raised above neutrality, generally reaching a solubility minimum in the range of 8.5 to 10.

The ability of brine to transport radionuclides could be greatly reduced if the pH of any brine that accumulates in the repository is raised from the ambient value of around 6.1 to a value that is closer to the solubility minimum range. Engineered alternatives that buffer the pH to a higher, more favorable value by the addition of lime (calcium oxide, or CaO) or portland-type cement (which contains a major percentage of hydrated lime [portlandite, or $Ca(OH)_2$]) to either the drum contents or backfill, are expected to result in improved performance because of lower actinide solubilities.

Sorption of Actinides on Backfill Material

Clay materials have a well known affinity under certain conditions to adsorb actinides. The net effect of this process is usually to either permanently immobilize the actinide, or retard the migration of the actinide relative to the average flow rate of a non-sorbing solute. In the repository, this retardation can provide additional time for radioactive decay to occur, thus reducing the total activity released.

A large amount of experimental data on sorption of radionuclides on clay minerals exists, however, most of this information is only applicable to dilute groundwater. Salado brines have extremely high concentrations of Mg^{+2}, K^+, Na^+, Cl^-, SO_4^{-2}, etc. Total dissolved solids in Salado brines are in the range of 370,000 mg/l compared to values in the range of 1,000 mg/l or less for drinking water. Sorption processes in the presence of these brines are quite different than processes occurring in dilute groundwater. No data was found to be available to simulate sorption of actinides on clay minerals in the presence of Salado brines, so this process was not considered. This approach is consistent with the SNL PA methodology which also concluded that "data to quantify actinide sorption on the various substrates under WIPP-specific physicochemical conditions are not available", and that "predicting sorption under WIPP-specific conditions is not feasible" (SNL, 1995).

The net effect of not considering this process is to minimize the predicted effectiveness of EAs that involve the addition of clay to the drums or backfill. The effects of clay on reducing initial void volume and decreasing the permeability of the waste/backfill composite are considered.

3.1.2 Methodology Used to Evaluate Factor 1

This section provides a description of the conceptual model of long-term repository performance that serves as the basis for the DAM. The numerical implementation of the conceptual model is described in Appendix E. The section concludes with a listing of the input parameter values and description of the criteria used to evaluate the effectiveness of alternatives during human intrusion events.

3.1.2.1 General Description of the Processes Simulated by the Design Analysis Model

The DAM was originally developed for the EATF (DOE, 1991a) and was subsequently updated for the EACBS. The DAM simulates processes occurring in the repository (rooms, panels, access drifts, and shaft seals) for the 10,000-year regulatory period defined in 40 CFR Part 191 (EPA, 1993) under both undisturbed and disturbed (human intrusion) conditions.

The behavior of the repository as simulated by the DAM is divided into the following time periods:

- Repository under Atmospheric Pressure—During this time atmospheric pressure is maintained within the repository.

- Repository Pressurization from Atmospheric to Peak Pressure—This phase is characterized by the processes associated with increasing gas pressure and presence of brine.

- Repository after Peak Pressure—This phase is characterized by the long-term processes that continue once peak pressures are reached in the repository, interrupted only by a human intrusion event.

The processes simulated by the DAM are discussed in detail in Appendix E.

Repository under Atmospheric Pressure

The excavation of underground openings at the WIPP horizon results in a predictable disturbance of the equilibrium state of the Salado. This deviation from equilibrium causes creep closure of the surrounding salt, resulting in the formation of a DRZ adjacent to surrounding openings. Creep closure is the viscoplastic response towards equilibrium by the rock under a deviatoric stress. Deviatoric stresses are the normal and shear stresses that remain after subtracting a hydrostatic stress, equal to the mean normal stress, from each normal stress component (Goodman, 1980).

The DRZ is defined as the zone of rock in which mechanical properties and hydrologic properties have changed in response to the excavation. The term "near-field" is used to describe the zone of rock within the DRZ, and the term "far-field" is used to describe the rock outside the DRZ in which intrinsic parameters such as porosity and permeability are undisturbed from pre-excavation values. Observations have defined a DRZ extending laterally throughout the excavation and varying in thickness from 1 to 5 meters, depending on the size and age of the opening. The "disturbed" zone exists above and below the repository (Figure 3-1), while the "intact" zone is undisturbed, and exists beyond the area affected by the excavations.

A panel, consisting of seven rooms and associated access drifts, will be filled with the waste containers (either drums or boxes). In most of the EAs that were evaluated, a backfill material (e.g., salt, clay, or grout) is used to fill the space around and between the waste containers. The waste and backfill material is referred to as "waste/backfill composite" or "composite". The purpose of adding the backfill varies depending on the alternative. Reasons for including backfill include: minimizing void volume in the room, reducing the permeability of the composite, increasing the shear strength of the composite, absorbing brine, and controlling the pH of any brine that may come in contact with the waste. Dry backfill is assumed to be emplaced at a 50 percent void space, and wet backfill (grout) is assumed to be emplaced at an 80 percent void space.

During excavations and waste emplacement, atmospheric pressure is maintained within the repository. Since the atmospheric pressure is substantially lower than the lithostatic pressure in the surrounding rocks, a depressurization of the Salado around the repository will occur. This will be manifested by a gradual decrease in pressure from the far-field pore pressure in the intact Salado to atmospheric pressure in a panel. Naturally occurring gas (nitrogen and methane) is present in brine from the Salado, and has been observed to exsolve from the brine in response to depressurization.

Underground experience at the WIPP with the presence and movement of brine within the Salado has yielded an understanding of brine movement in salt. The presence and movement of brine

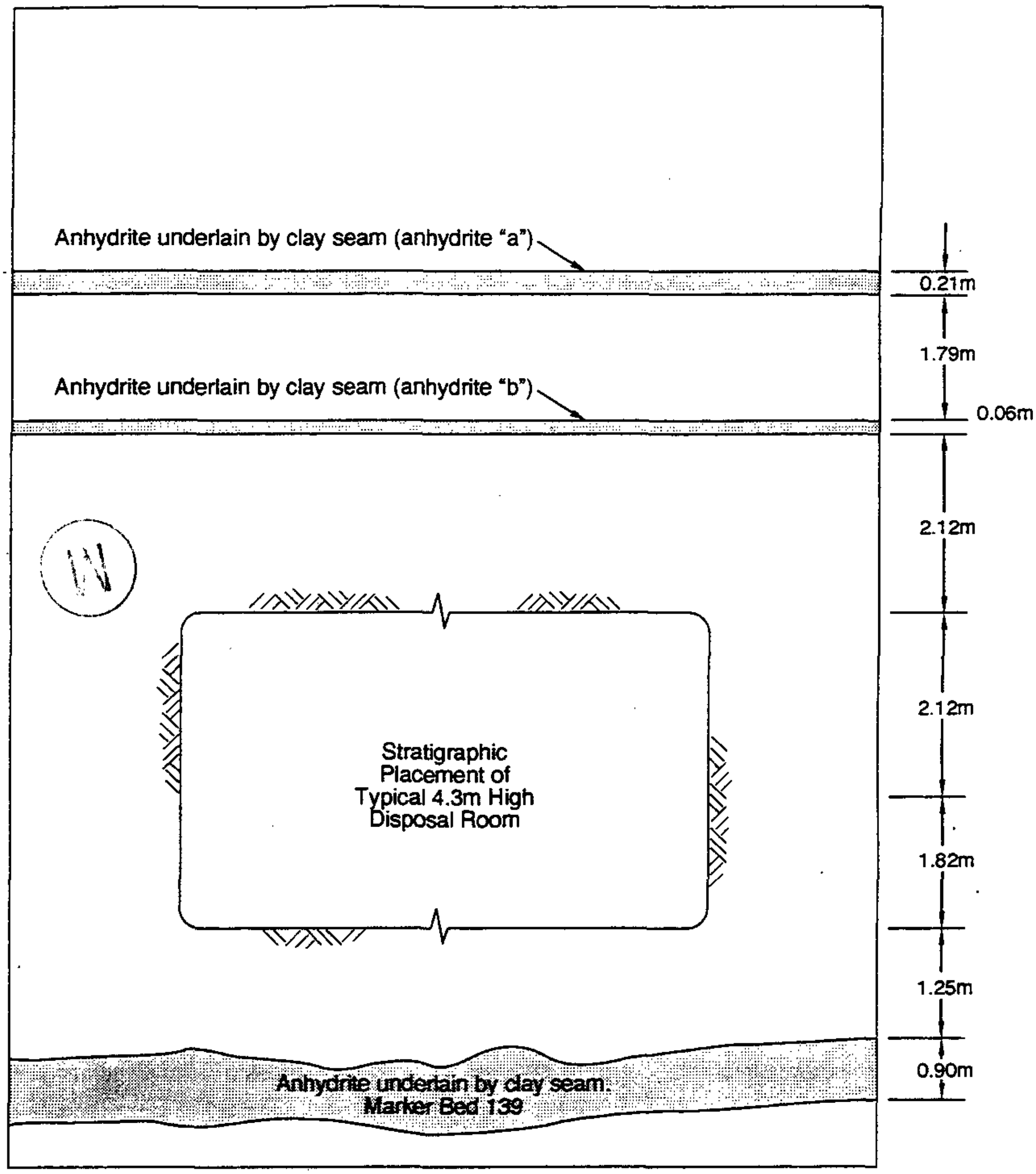


Figure 3-1
Stratigraphy at the Repository Horizon (Modified from Lappin et al. [1989])

in the Salado adjacent to the underground workings is evidenced by small "weeps" (brine encrustations) that commonly develop on the walls of an excavation shortly after it is mined. These "weeps" are a result of the difference in pressure between the surrounding halite and the atmospheric pressure within the rooms, and cease over time. In general, the brine inflow rate is less than the evaporation potential caused by mine ventilation, resulting in humid, but brine-free conditions in the repository.

In-situ brine flow experiments are used to measure the permeability of the Salado. The brine flow rates into sealed boreholes are in the range of 0.43 gallons (1.64 L)/yr to 0.792 gallons (3 L)/yr as steady states are approached. These rates have been used to calculate far-field Salado permeabilities that fall within the range of 10^{-21} to 10^{-20} m^2, using a poroelastic Darcy flow model (Lappin et al., 1989). On the basis of preliminary data, the far-field permeability of the anhydrites appears to be one to three orders of magnitude higher than that of the intact pure halite.

Emplacement of the waste within a panel is followed by closure of the access drifts and finally, sealing the shafts with a multi-component seal system. The goal of the sealing system is to limit groundwater from the overlying units from flowing down the shafts, and limit brine and/or gas from flowing up the shafts. This objective is accomplished by a combination of short-term seals in the form of concrete plugs, and long-term seals in the form of salt that has reconsolidated due to creep closure.

Repository Pressurization from Atmospheric to Peak Pressure

As long as the generated stress results in pressures below lithostatic within the repository, the Salado will continue to creep due to deviatoric stresses, thereby reducing the room dimensions.

The creep will continue and could eventually compact the waste/backfill composite. At some point the closure force will be resisted by the combination of two different mechanisms. The first of these is the ability of the particular waste/backfill composite to physically function to resist the force of compaction, manifested by its effective stress. A calculation of the effective stress and other properties is discussed in Appendix F. The effective stress is the stress that is transferred between the solid particles of the waste/backfill composite. The other mechanism is the effect of gas pressure within the void spaces. The increasing gas pressure provides a second component of internal stress resisting creep. As creep ceases, additional development of the DRZ will cease and may actually begin to reverse as fractures induced during the formation of the DRZ will begin to heal.

The small amounts of brine will continue to migrate toward the panels as long as there is an adequate pressure differential between the waste disposal panels and the undisturbed Salado. As described previously, corrosion of drums and metals in the waste under anoxic conditions will consume brine (if present), producing hydrogen gas in the process which contributes to pressurization. In addition, microbial activity is assumed to consume cellulosic materials (paper and wood), and perhaps other organic materials (plastic and rubber) in the waste as well, producing carbon dioxide and methane, and to a lesser extent nitrogen, hydrogen sulfide, hydrogen, and carbon monoxide. The hydrogen sulfide will probably be consumed by reacting with the metals or their corrosion products to form sulfide minerals. Radiolysis of brines, cellulosic materials, plastics, and rubbers will consume water and degrade the organics to produce limited amounts of hydrogen, oxygen, carbon monoxide gas, and carbon dioxide. Carbon dioxide may be removed from the gas phase by reacting with cementitious materials present as part of the waste or backfill to form carbonate minerals (calcite, siderite, magnesite, etc.). The combination of gas generation due to the mechanisms described above, and the decrease in void volume due to creep closure, will result in pressurization of the panels.

Increased gas generation will increase the partial pressures of the gases and their solubilities in brine. This will cause additional gas to dissolve in the brine that may be present in the room. The increased concentration of gases in the brine will be the driving force for diffusion of gases into the intact Salado.

In addition to diffusion, advection into the Salado could occur as the gas pressure increases within the panel. This process involves the migration of gases under a pressure gradient from the room into the more permeable anhydrite units adjacent to the underground openings. The ability of these Salado units to advect gases will depend on: (1) the intrinsic permeability of each unit; (2) the relative brine and gas saturations of these units; (3) any capillary or threshold-pressure effects involved in gas displacement of brine already present; and (4) the amount of localized depressurization which exists due to the operational phase. Ongoing work suggests the threshold-pressure within the intact Salado halites may be as high as 8 megaPascal (MPa). Therefore, the sum total of the threshold pressure and the in-situ pore pressure will probably prevent gas advection into the halite. However, if some fractures exist within the DRZ that connect the panel to the anhydrite beds, gases will be dissipated due to the higher permeability (therefore lower threshold pressure) of the anhydrite units. Advective processes would allow some gas to escape from the panels, thus lowering the pressure in the disposal rooms.

The proposed short-term seals consisting of concrete plugs and possibly clay materials are designed to function for approximately 100 years after decommissioning. The long-term seals are made of crushed salt that is chemically and mechanically compatible with the host rock formation. Creep closure of the surrounding intact host rock consolidates and densifies the crushed salt to a condition comparable to the preexcavation intact salt.

Repository after Peak Pressure

No further brine inflow would take place once the pressures in the panel equal or exceed the far-field pressure of the Salado. Any brine accumulated in the panel would continue to be consumed at some rate by anoxic corrosion and would facilitate microbial degradation, assuming corrodible metals and organic materials are still present in the facility. These gas generation processes could, under some sets of conditions, create a peak pressure exceeding lithostatic. In addition, once the water present in the brine is consumed, reactions of carbon dioxide with cementitious materials would also cease, since these reactions require water.

The mechanical resistance to closure prevents further creep during the late phase, resulting in a cessation of waste/backfill compaction. This mechanical resistance is made up of two components: (1) the stress of compaction and (2) the interstitial fluid pressure. When the sum total of these components becomes greater than the lithostatic pressure, the deviatoric stresses are eliminated and creep ceases. At this point, the void volume becomes fixed at a constant value.

Gas advection will continue as long as the pressure within the panel is such that a driving force into the Salado is maintained. Once the pressure in the repository returns to lithostatic, the driving force is terminated and the system reaches a steady state condition.

Radionuclide Release Rate From Waste

A solubility-limited source term was assumed in the model. The assumption, which is consistent with the Sandia PA approach, presumes that any brine that contacts the waste immediately dissolves the five actinide elements at concentrations equal to their solubilities in brine, provided that sufficient actinide inventory is available. This is a reasonable assumption for untreated waste, because the actinides are mostly present as surface contamination, and are readily available for dissolution by intruding brine. The assumption may be less reasonable for plasma-processed waste because the actinide release rate from this waste form may be limited by the dissolution rate of the glass. The solubility-limited approach for the plasma processing alternative was still used because the leach rate of this waste form in WIPP brine is unknown.

Radionuclide Solubility

Solubility data on actinide-bearing solids were compiled for this study from published experimental investigations to estimate radionuclide concentrations in brine contacting TRU waste. Based on the most recent revision of the BIR for WIPP (DOE 1995e), actinides of interest that have isotopes with half-lives of 20 years or more are Th, U, Np, Pu, and Am, which occur in the waste primarily as oxides (Weiner, 1995). The remaining radionuclides summarized in the WTWBIR have very short half lives (less than 6 years) or are present in quantities insufficient to affect the release limits allowed under 40 CFR §191.13. Therefore, the radio-elements considered in the Factor 1 analysis are limited to Th, U, Np, Pu, and Am solids.

A discussion on radionuclide solubility is presented in Appendix G and Appendix H. This discussion is divided into two parts: 1) a summary of literature studies on the actinides of interest (Appendix G) and 2) a summary of the statistical approach used to select the mean solubility values and their 95 percent confidence intervals for Th, U, Np, Pu, and Am at the pH values of interest (Appendix H).

Two pH values are of interest for the EACBS solubility analysis: a pH of 6.1 (baseline), which corresponds to the average pH values observed in indigenous Salado brine, and a pH of 8.3, which is the approximate pH established in Salado brine by the brucite ($Mg(OH)_2$) buffer when a limited amount of lime is added to the backfill. Specific information on the effects of the addition of lime on the pH of Salado brine is presented in Appendix H.

3.1.2.2 Input Parameter Values Used in Factor 1 Analysis

This section provides listings of the input parameter values that were used in the DAM for the baseline case and each of the EAs. Table 3-1 is a list of input parameter values that are the same for each of the EAs. Table 3-2 is a list of parameter values that change for some or all of the EAs. The definition and unit of measure for each parameter in both tables are provided as footnotes at the end of each table.

3.1.2.3 Criteria Used to Evaluate Effectiveness of Alternatives

This section describes the criteria used to evaluate the effectiveness of alternatives in improving repository performance under human intrusion scenarios.

1 **TABLE 3-1**

LIST OF CONSTANT PARAMETERS USED IN THE DESIGN ANALYSIS MODEL

Parameter[a]	Value	Parameter[a]		Value
CB	0.596875		Hydrogen	0
KANH	18		Nitrogen	0.25532
PANH	10.36		Oxygen	0
TEMP	300	RATIO	Carbon Dioxide	0.42553
PF	146.10		Carbon Monoxide	0
NU	4.95		Water	0
CW	0.5523E-18		Methane	0.31915
CH	0.1464E-18	RHTORW		0.7
HHUMRATE	0.0	RBOR		0.177500
HINURATE	0.6	TIMBORHOL		4,999
BHUMRATE	0.01	PTHL		91.440002
BINURATE	0.1			
BIOSTOIC	0.835			

[a]Footnotes:

CB	=	Brine inflow rate at atmospheric pressure (in cubic meters per panel per year).
KANH	=	Negative log of the permeability of anhydrite (in square meters).
PANH	=	Pore pressure in anhydrites (in kiloPascals).
TEMP	=	Room temperature (in Kelvin).
PF	=	Lithostatic pressure plus tensile strength of intact salt (in atmospheres).
NU	=	Stress constant (unitless).
CW	=	Horizontal strain rate (unitless).
CH	=	Vertical strain rate (unitless).
HHUMRATE	=	Rate of hydrogen gas generation due to anoxic corrosion of metals under humid conditions (in moles of hydrogen per drum of waste per year).
HINURATE	=	Rate of hydrogen gas generation due to anoxic corrosion of metals under inundated conditions (in moles of hydrogen gas per drum of waste per year).
BHUMRATE	=	Rate of microbial gas generation under humid conditions (in moles of biogas per kilogram of cellulosics per year).
BINURATE	=	Rate of microbial gas generation under inundated conditions (in moles of biogas per kilogram of cellulosics per year).
BIOSTOIC	=	Stoichiometry factor for microbial gas generation process (in moles of biogas generated per mole of cellulosics consumed).
RHTORW	=	Stoichiometry factor for anoxic corrosion process (in moles of hydrogen gas generated per mole of water consumed).
RBOR	=	Radius of borehole (in meters).
RATIO	=	Mole fraction of given gas generated microbially (unitless).
TIMBORHOL	=	Time of intrusion (in years).
PTHL	=	Distance between boreholes for the E1E2 intrusion scenarios (in meters).

TABLE 3-2

LIST OF VARYING PARAMETERS USED IN THE DESIGN ANALYSIS MODEL

	Parameter[a]									
EA	Width	Height	Length	VPNL	DENSINIT	VB	MOLCAOH2	WSTPOR	E0	ADIF
Baseline	10.05840	3.96240	91.44	45,700	0.01071	0.0	7.2E+05	0.90753	4.86848	31,756
1	10.05840	3.96240	91.44	45,700	0.02035	0.0	7.2E+05	0.82625	2.12332	31,756
6	10.05840	3.96240	91.44	45,700	0.01362	0.0	7.2E+05	0.88369	3.6656	31,756
10	10.05840	3.96240	91.44	45,700	0.03155	0.0	0.00	0.78524	1.52840	31,756
33	10.05840	3.96240	91.44	45,700	0.03248	0.0	7.2E+05	0.67661	1.65587	31,756
35a	10.05840	3.96240	91.44	45,700	0.04265	186.2	2.0E+08	0.58205	1.25758	31,756
35b	10.05840	3.96240	91.44	45,700	0.04265	186.2	2.0E+08	0.58205	1.25758	31,756
77a	10.05840	1.82880	91.44	21,093	0.05552	109.2	1.2E+08	0.45717	0.75743	27,077
77b	10.05840	1.82880	91.44	21,093	0.03237	0.0	402,053	0.68561	1.81487	27,077
77c	10.05840	1.82880	91.44	21,093	0.04465	0.0	402,053	0.55545	0.99069	27,077
77d	10.05840	1.82880	91.44	21,093	0.03640	0.0	2.2E+07	0.58309	1.12269	27,077
83	10.05840	3.96240	91.44	45,700	0.02658	0.0	3.4E+07	0.69637	1.82875	31,756
94a	10.05840	3.96240	91.44	45,700	0.01461	0.0	1.4E+07	0.87625	3.38930	31,756
94b	10.05840	3.96240	91.44	45,700	0.03567	0.0	1.4E+07	0.65108	1.46194	31,756
94c	10.05840	3.96240	91.44	45,700	0.04584	186.2	2.2E+08	0.55661	1.12818	31,756
94d	10.05840	3.96240	91.44	45,700	0.04584	186.2	2.2E+08	0.55661	1.12818	31,756
94e	10.05840	3.96240	91.44	45,700	0.02690	0.0	1.4E+07	0.74404	2.35614	31,756
94f	10.05840	3.96240	91.44	45,700	0.02978	0.0	4.7E+07	0.67082	1.60961	31,756
111	10.05840	3.96240	91.44	45,700	0.02370	0.0	7.2E+05	0.76966	2.72883	31,756

TABLE 3-2 (Continued)

LIST OF VARYING PARAMETERS USED IN THE DESIGN ANALYSIS MODEL

	Parameter[a]									
			RADSOL							
EA	Plutonium	Uranium	Americium	Neptunium	Thorium	CLRNC	NDE	H2MAX	BIOMAX	RADFRAC
Baseline	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	1.29	80,519	7.0E+07	3.0E+06	3.00
1	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	2.46	45,194	8.2E+07	3.0E+06	1.50
6	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	1.72	67,478	8.2E+07	3.0E+06	2.60
10	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	3.08	26,585	3.7E+07	303.3	1.00
33	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	7.0E+07	3.0E+06	3.00
35a	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	7.0E+07	3.0E+06	2.00
35b	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	7.0E+07	3.0E+06	2.00
77a	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.36	25,080	4.6E+07	1.7E+06	1.50
77b	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.36	25,080	4.6E+07	1.7E+06	1.50
77c	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.36	25,080	4.6E+07	1.7E+06	1.50
77d	1.0E-07	3.98E-03	3.16E-04	1.99E-04	5.0E-08	0.36	25,080	4.6E+07	1.7E+06	1.50
83	1.0E-07	3.98E-03	3.16E-04	1.99E-04	5.0E-08	0.71	80,519	7.0E+07	3.0E+06	3.00
94a	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	1.29	80,519	9.5E+07	3.0E+06	2.30
94b	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	9.5E+07	3.0E+06	2.30
94c	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	9.5E+07	3.0E+06	1.75
94d	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	9.5E+07	3.0E+06	1.75
94e	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	9.5E+07	3.0E+06	2.30
94f	1.0E-07	3.98E-03	3.16E-04	1.99E-04	5.0E-08	0.71	80,519	9.5E+07	3.0E+06	2.30
111	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	85,019	7.0E+07	3.0E+06	3.00

TABLE 3-2 (Continued)

LIST OF VARYING PARAMETERS USED IN THE DESIGN ANALYSIS MODEL

[a]Footnotes:

Width	=	Room width (in meters).
Height	=	Room height (in meters).
Length	=	Room length (in meters).
VPNL	=	Volume of panel (in cubic meters).
DENSINIT	=	Initial waste density (in pounds per cubic inch).
VB	=	Initial brine volume (in cubic meters).
MOLCAOH2	=	Moles of calcium hydroxide present in a panel (in moles of calcium hydroxide per panel).
WSTPOR	=	Porosity of the waste and backfill at zero stress (unitless).
E0	=	Initial void ratio (unitless).
ADIF	=	Total surface area for diffusion (in square meters).
RADSOL	=	Radionuclide solubility (in moles per liter).
CLRNC	=	Initial clearance between waste stack and roof of room (in meters of air gap).
NDE	=	Number of drum-equivalents per panel (unitless).
H2MAX	=	Maximum moles of hydrogen generated from anoxic corrosion (in moles of hydrogen).
BIOMAX	=	Maximum biogas potential based on amount of cellulosics present (in kilograms of cellulosics per panel).
RADFRAC	=	Erosion factor used to calculate the effective radius of a borehole as a means for determining quantity of waste in cuttings (unitless). RADFAC x RBOR = effective radius.

Describing the release of radionuclides from the disposal system can be complex because the five actinides of concern have different solubilities, and the specific isotopes of concern have different inventories and half-lives. A convenient method of describing release is through the use of an equation termed the "EPA sum rule". This equation can be expressed as:

$$Q = \Sigma \left[\frac{Q_i}{RL_i} \right], \qquad 3.5$$

where:

- Q = Total normalized release
- Q_i = Predicted release of isotope i
- RL_i = Release limit for isotope i.

This equation expresses the combined normalized release of each isotope of concern as a single value, which is convenient for comparison of the various alternatives with the baseline. The *release limit term* RL_i *is based on the individual isotope release limits provided in 40 CFR 191,* which allows a certain number of "units" of release of each isotope normalized to the total inventory of alpha-emitting transuranic isotopes with half-lives greater than 20 years (EPA, 1985).

For each EA, separate Q values are calculated for the cuttings release and the groundwater pathway for each of the three scenarios, providing four Q values for each EA. The Q values for cuttings release are based on the volume of cuttings brought to the surface, and the activity of each radionuclide contained in that volume. The model considers the density of the exhumed waste, compaction of the waste from creep closure, radionuclide decay, and contributions from erosion of the waste surrounding the borehole by circulating drilling fluid.

Cuttings releases from each of the three scenarios are based on the assumption that each scenario occurs one time at 5,000 years after facility closure. These predicted releases cannot be directly compared to the EPA Standard because the results are not weighted by the probabilities of scenario occurrence as the Standard requires.

The Q values for the groundwater pathway are also based on a cumulative 5,000 year release, assuming that each scenario occurs one time at 5,000 years after facility closure. Releases are calculated from the cumulative flux of each radionuclide into the Culebra at the point of borehole intersection. These predicted releases to groundwater cannot be compared with the EPA Standard for two reasons. As is the case with the cuttings release, the results are not weighted by the probabilities of scenario occurrence. In addition, results are based on cumulative radionuclide flux into the Culebra, whereas the Standard considers cumulative radionuclide flux *across the 16 square mile (41.42 square kilometer) land withdrawal boundary. Thus, any* attenuation of radionuclides within the Culebra along a flow path from the point of borehole intersection to the land withdrawal boundary from processes including advection, dispersion, retardation, matrix diffusion, and decay, are not considered in the model.

A parameter called the "Measure of Relative Effectiveness" (MRE) was then defined using the DAM for each alternative, scenario, and mode of release (cuttings and groundwater pathway) in order to quantitatively compare the relative merits of each alternative with respect to human intrusion events. This factor is a measure of the relative improvement in the performance of the alternative design, compared to the baseline design. The ratio of the cumulative release of radionuclides for an engineered alternative to the release under baseline conditions is the MRE for that particular alternative. In other words:

$$\text{Measure of Relative Effectiveness} = \frac{\text{Normalized Cumulative Release of Radionuclides Using the Alternative Design}}{\text{Normalized Cumulative Release of Radionuclides Using the Baseline Design}} \qquad 3.6$$

or

$$MRE = \frac{Q_{Alternative}}{Q_{Baseline}} \qquad 3.7$$

Six MREs are calculated for each scenario, consisting of cuttings and groundwater pathway releases for each of three scenarios (E1, E2, and E1E2). For the baseline, the MRE is equal to 1. The lower the value of this factor, less than 1, the more effective the alternative is in improving repository performance relative to the baseline. Values greater than 1 indicate that the alternative yields higher radionuclide releases than the baseline design.

The MREs provide an accurate measure of the relative changes in long-term performance, even though they are calculated from Q values that do not address EPA requirements for the consideration of the probability of release scenarios. The absolute Q values do not consider the probability of scenario occurrence, but none of the alternatives affect those probabilities. Since the MRE is calculated as a ratio of Q values, the effects of scenario probabilities cancel, yielding an accurate relative index. Likewise, the absolute Q values for the groundwater pathway do not consider the effects of radionuclide transport processes in the Culebra, but none of the EAs affect those processes. Since the MRE is calculated as a ratio of Q values, the effects of those Culebra transport processes cancel, yielding an accurate relative index.

3.1.2.4 Comparison between the SNL Performance Assessment Model and the Engineered Alternatives Design Analysis Model

Most of the conceptual models and input parameter values used in the EA study were based on the SNL performance assessment (PA) approach as documented in the SNL 1992 PA Update (SNL, 1992) and the SNL System Prioritization Method Position Papers. The majority of the differences between the EA and PA approaches are required by the relative nature of the EA approach compared to the absolute nature of the SNL PA model. The goal of the EA study is to quantify the relative differences in performance between the baseline case and the various alternatives. This is achieved by calculating a measure of relative effectiveness (MRE) for each alternative which is a measure of the extent to which the EA increases or decreases the cumulative 10,000-year radionuclide release relative to the baseline case.

The goal of the PA methodology is to quantify the predicted performance of the baseline case for comparison against the requirements of 40 CFR 191. This is achieved by calculating the cumulative 10,000 year radionuclide release.

Several processes simulated in the PA model have significant effects on absolute results but little to no effects on relative results. These processes have not been included in the DAM. Specific differences between the PA and EA models are discussed below.

Human intrusion probabilities—The PA model randomly selects intrusion times based on a general failure rate function that is described using a Poison distribution. This is required to quantify the absolute cumulative 10,000-year release. The DAM assumes that each of the three intrusion scenarios occur once at 5000 years after facility closure. None of the alternatives evaluated by the EA study affect the rate or frequency of intrusions, so the probability and rate of intrusion are considerations that can be neglected by the EA study (see Section 3.1.3.1). Doubling the rate of intrusion will roughly double the absolute predicted releases, but will not change the relative benefits offered by an EA.

Spatial domain—The PA model predicts the cumulative 10,000-year radionuclide release across the 16 square mile (41.42 square kilometer) land withdrawal boundary. This requires simulating groundwater flow and radionuclide transport process that will occur along potential flow paths through the Culebra Dolomite from the point of borehole intersection to the unit boundary. The DAM predicts the cumulative 10,000-year radionuclide release into the Culebra at the point of borehole intersection and does not consider processes in the Culebra. None of the alternatives evaluated by the EA study affect flow or transport in the Culebra so the attenuation of radionuclide within the Culebra does not change the relative benefits offered by an EA.

Gas generation rates—For gas generation rates, the "expected" values for humid and inundated conditions cited in the Gas Generation Position Paper (November 15, 1994 Draft) was used as the median values in the DAM but the ranges from the position paper were not. The range of values in the SNL Position Paper for microbial gas generation in an inundated environment is 0 to 5 moles/drum/yr (m/d/y). This range represent the possible range of values for an individual randomly selected drum. It is inappropriate to sample on this range if there are 85,000 drums in a panel that are in communication with each other. The probability of all 85,000 drums generating gas at a rate of 5 m/d/y is insignificant. In addition, the high generators will tend to cancel the low generators. Under these conditions, the appropriate range to sample on is a measure of the error of the mean rather than the full range of possible values for individual drums.

Radionuclide solubilities—For radionuclide solubilities, the Actinide Source Term Position Paper (March 31, 1995 draft) discusses several different conceptual models but recommends the *Inventory Limits with Realistically Conservative Maximum Concentrations Model*. This model assumes large arbitrary values and does not consider the effects of changing pH. Some of the alternatives utilize pH buffers (CaO or portland grout) to raise the pH of brine that may come in contact with the waste and thereby reduce actinide solubilities. The EA study requires a source term approach that can assess the effects of pH shifts on actinide solubilities. The selected approach was to base solubilities on published experimental values in brine or saline systems as a function of pH. A summary of the published experimental values is provided in Appendix G, and the statistical analysis and results of the experimental data evaluation is provided in Appendix H.

Release of drill cuttings during human intrusion events—One component of release during human intrusion events is the direct transport of waste to the surface by the action of an exploratory drill bit. The SNL PA methodology considers three separate physical processes that can influence the quantity of waste brought to the surface by drilling events. These processes are:

- Cuttings—waste contained in the cylindrical volume created by the cutting action of the drill bit passing through the waste
- Cavings—waste that erodes from the borehole wall in response to the upward-flowing drilling fluid within the annulus
- Spallings—waste introduced into the drilling fluid caused by the release of waste-generated gas escaping to the lower-pressure borehole.

The SNL PA model plans to considers all three of the above processes but currently only the first two are implemented (Butcher et al., 1995). The DAM also only considers the first two of the above processes.

3.1.3 Results of Analysis of Factor 1

Results of long-term performance are provided in Table 3-3.

Discussion and interpretation of the human intrusion results and their uncertainties is provided in detail in Section 3.2.

3.1.3.1 Effects of Intrusions at Times Other Than 5000 Years

The absolute quantitative releases from human intrusion events are dependent on the timing, probability, and frequency of the events. However, the relative benefits of the EAs (as calculated by the MREs) are not very sensitive to the timing of the EAs and are totally independent of the probabilities and frequencies of the events.

Comparisons of the alternatives are based on the assumption that each of the three human intrusion events occur once at 5000 years. The effects of this simplifying assumption was evaluated by performing additional simulations for the baseline and nine selected alternatives at 200, 2000, and 7000 years. The results of this limited sensitivity analysis on the effects of intrusion time are discussed below for each scenario.

Cuttings release—The calculated MREs from cuttings release is the same at 2000, 5000, and 7000 years. The MREs at 200 years differ by several percent from the MREs at later years because the composite material in the rooms at 200 years is still in the process of consolidating from creep closure, and this consolidation occurs at differing rates for each alternative. Consolidation of the composite material is complete by 2000 years, so the MREs remain constant thereafter.

E1 groundwater pathway scenario—The E1 (Castile brine) scenario MRE results are also sensitive to time in the early years because of on-going compaction and the effects of compaction on permeability. Once the composite material fully compacts, the permeability reaches a constant value and results are insensitive to time.

1 **TABLE 3-3**

MEASURE OF RELATIVE EFFECTIVENESS FOR RELEASES TO THE CULEBRA DOLOMITE AND TO THE SURFACE UNDER THE THREE INTRUSION SCENARIOS

			Normalized Quantity Transported to Culebra Dolomite (by Intrusion Scenario)			Normalized Quantity of Radionuclides Released to Surface Through Cuttings for Each Intrusion Scenario
Waste Processing	Backfill	Engineered Alternative Number	E1	E2	E1E2	E1, E2, or E1E2
None	None	Baseline	1.0	1.0	1.0	1.0
	Sand & Clay	33	0.74	2.0	0.99	0.92
	SAG	35a	0.40	1.1	0.040	0.40
	CG	35b	0.40	1.1	0.040	0.40
	Clay	111	0.54	2.1	0.56	0.94
	CaO & Salt	83	0.83	0.30	0.05	0.94
Super C	None	1	0.93	1.4	1.00	0.26
	SAG	77a	0.44	0.56	0.083	0.21
	Clay	77b	0.56	2.3	0.93	0.22
	Sand & Clay	77c	0.73	2.1	0.98	0.21
	CaO & Salt	77d	0.79	0.30	0.032	0.22
S & C	None	6	0.95	1.1	1.0	0.79
EC/SC	None	94a	0.69	1.1	1.0	0.57
	Sand & Clay	94b	0.66	0.86	0.99	0.52
	CG	94c	0.45	0.46	0.089	0.30
	SAG	94d	0.45	0.46	0.089	0.30
	Clay	94e	0.53	0.88	0.49	0.53
	CaO & Salt	94f	0.67	0.30	0.012	0.54
Plasma	None	10	0.00078	0.0093	0.00076	0.12

LEGEND:
- Super C: Supercompaction of all waste, except sludges
- S&C: Shredding and compaction of all waste, except sludges
- EC/SC: Enhanced cementation of sludges. Shred and add clay based materials to organics and inorganics
- SAG: Salt aggregate grout
- CG: Cementitious grout

M

Consolidation of the composite material is complete by 2000 years, so the MREs remain constant thereafter.

E2 groundwater pathway scenario—No releases are predicted for the E2 scenario until the fluid pressure in the room is sufficient to transport brine to the level of the Culebra. At 200 years, the pressure is too low to drive releases, but by 2000 years, pressure is high enough to yield releases. MREs remain constant after that point.

E1E2 groundwater pathway scenario—All three of the scenarios evaluate flow releases over the time frame of intrusion until the 10,000-year regulatory limit. An intrusion at 5000 years allows 5000 years of flow to occur, but an intrusion at 7000 years allows only 3000 years of flow to occur. In the case of the E1E2 scenario, the flow occurs between two boreholes within a panel.

Depending on the cumulative volume of brine flow that occurs, the radionuclide releases from each alternative fall into two categories: inventory-limited releases and solubility-limited releases. Inventory-limited releases occur when a large enough cumulative volume of brine flows through the affected portion of waste to cause the release of the entire actinide inventory in the affected volume of waste over the regulatory period of performance. Solubility-limited releases occur when brine flow rates or radionuclide solubilities do not allow the entire inventory within the affected volume to be released over the regulatory period of performance.

Results for the baseline case at all times evaluated (200, 2000, 5000 and 7000 years) show inventory-limited releases. Results for some of the alternatives (33, 1, 6, and 94a) also show inventory-limited releases for the E1E2 scenario at all times evaluated. The MREs for these alternatives do not show a dependence on time of intrusion because an inventory-limited release for the alternative is divided by the inventory-limited release for the baseline, yielding a constant ratio that is independent of time.

Other alternatives (83 and 10) have MREs that show a sensitivity to time of intrusion because the releases for these alternatives are solubility-limited. When a release that is a function of brine flow or radionuclide solubility is compared to a release that is a function of inventory, the time over which the release takes place becomes a sensitive variable. Under these conditions, the MRE decreases (improved performance) at later years because the window of time over which cumulative releases are integrated is shorter.

The results of this sensitivity analysis show that in general, the MREs are insensitive to the time of intrusion once the physical properties (density and permeability) of the composite material in the room reaches a steady-state condition. This occurs sometime between 200 and 2000 years. One exception is the results of the E1E2 scenario for some alternatives. For these cases, the improvement offered by those alternatives relative to the baseline case increases when the intrusion event occurs at later years. Even for these alternatives, performing the comparisons at times other than 5000 years would not change the relative ranking of the MRE results.

3.2 FACTOR 2: UNCERTAINTY IN COMPLIANCE ASSESSMENT

3.2.1 Definition of Factor 2

Factor 2 estimates the EA's ability to treat uncertainty relative to the quantity of radioactive materials that will be transported to the accessible environment as a result of scenarios that intrude into the disposal system. The results of Factor 2 may then be used in conjunction with those of Factor 1 to characterize capability of an EA to provide additional assurance that the disposal system complies with the requirements of 40 CFR 191.13(a).

Treatment of uncertainty in compliance assessment can be realized by reducing both the quantity of radioactive materials released to the accessible environment and the statistical variability about that quantity. As described in Section 3.1, Factor 1 addresses the magnitude of reduction through the analysis of the MRE for cuttings removal to the surface and groundwater transport to the Culebra via the borehole, given scenarios E1, E2, or E1E2 occur. Factor 2 addresses the ability of the EAs to treat the uncertainty regarding these processes. By lowering the uncertainty of predictions of quantities of radioactive material that might be released as a result of an intrusion scenario, one can provide additional assurance in the prediction that the disposal system will perform as expected.

The EPA requires that the results of the formal performance assessment be incorporated, to the extent practicable, into a single complementary cumulative distribution function (CCDF) that indicates the probability of exceeding various levels of summed normalized releases (EPA, 1985). Several such CCDFs are provided in SNL, 1992. The mean MREs calculated by Factor 1 can be interpreted as the factor by which the entire group of CCDFs may shift to the left. The uncertainties calculated in Factor 2 relate to 1) the uncertainty in the mean MREs and 2) the degree to which the set of CCDFs may become less spread out. Because the largest improvement in assurance that adequate containment will be achieved derives from reducing the spread of large releases (which are closest to the EPA limit), the second measure calculates an MRE based on the factor by which the 95th percentiles of value of radionuclide transport are reduced by each EA.

3.2.2 Methodology Used to Evaluate Factor 2

A given EA might have an impact on one or more parameters that are important to repository performance. Because the physical processes expected to operate in the repository are nonlinear and interrelated, the impacts on uncertainty in the overall estimate of performance cannot be determined analytically by examining changes in the uncertainty assigned to any one input parameter. Therefore, the EACBS evaluation of uncertainty generates a series of input parameter sets using Monte Carlo techniques that randomly sample the parameters' probability distributions. The DAM then uses each set of input parameters to estimate the quantity of radioactive materials that will be transported across the immediate boundary of the WIPP repository, given each of the intrusion scenarios occur. The uncertainty results are then correlated to those for the baseline design so that comparisons can be made of the proposed EAs.

3.2.2.1 Uncertainty of Key Repository Performance Parameters

The analysis proceeds by first characterizing the uncertainty of important parameters of the waste and the disposal system that influence the long term performance of the repository. It then estimates how each EA's estimated physical characteristics treat uncertainty through impacting these parameters.

The quantity and rate of radionuclide movement will depend on the conditions produced by the intrusion event, the driving forces available at or near the repository, and the mobility of the waste in response to the driving forces. Input parameter uncertainty that impacts these processes includes the natural variability of materials used in the disposal system and uncertainty produced by the lack of sufficient data used to determine parameter ranges. Uncertainty is expressed by establishing distributions of the possible values for each of the parameters. Once a value is randomly selected from the distribution for a given sample calculation, it is assumed to remain at that value for the 10,000-year period of repository performance as calculated by the DAM.

First, the uncertainty in the state-of-knowledge regarding these parameters is assessed and represented by probability distributions in the STADIC Code, which is described in Appendix J. The definition of the probability distributions is done within a FORTRAN subroutine of STADIC. By further programming the subroutine, the analyst can explicitly account for physical correlations between the parameters by establishing dependencies in the sampling of their associated uncertainty distributions. STADIC generates random numbers using Monte Carlo subroutines and samples each of the probability distributions in accordance with the dependency rules established by the user-defined subroutine to produce a set of input values to the DAM code.

Given a set of input parameter values, the DAM calculates the evolution of conditions within the repository and the resultant transport of radioactive materials outside the immediate boundary of the repository for each of the three intrusion scenarios. The output of the DAM calculation is then stored with its associated input set as one trial of the Monte Carlo simulation. When a reasonable number of trials are accomplished (1,000 for this analysis), uncertainties in repository performance resulting from the uncertainties in the input parameters can be observed and analyzed. For this evaluation, 1,000 trials was judged to be reasonable. This produced a spectrum of results that clearly indicated trends and produced no discontinuous gaps in output.

3.2.2.2 Changes in Uncertainties Produced by an Engineered Alternative

Distribution of Overall MRE

As discussed in Section 3.1.2.2, the increased confidence in compliance assessment that would be achieved through implementing an EA is estimated by calculating two MREs for each intrusion scenario. These ratios are calculated individually for the two major mechanisms of radionuclide transport:

- MRE_{cut} — Measure of Relative Effectiveness for cuttings releases on the surface
- MRE_{wat} — Measure of Relative Effectiveness for reducing waterborne transport to the Culebra at the point of borehole intrusion.

An MRE is obtained by calculating the ratio of the cumulative release of radionuclides using the EA divided by the cumulative release of radionuclides with the baseline design. Values of an MRE that are less than one indicate that an EA will improve the long term performance of the disposal system. The net impact on a graph of the CCDF of the PA will be to move the consequences associated with intrusion scenarios to the left, thus reducing the impact of uncertainties in the assessment.

Using the Monte Carlo process, the physical parameters describing the baseline design and each of the EA's are each subjected to 1,000 performance calculations using the DAM computer code. To ensure that the comparisons will be based on the uncertainties in the anticipated changes in performance parameters and not differences in the random samples, the same random number seed is used to initialize the sampling of the input parameters of the baseline design and each of the EAs. The order in which random samples are taken remains constant across the baseline design and all EAs. The two MREs previously described are then calculated based on samples that used the same random numbers set in both the baseline and the EA. These calculations produce 1,000 values for each MRE. The distribution of these MRE values represents the uncertainties regarding the potential for performance improvement produced by each EA.

MRE for Reducing Larger Releases of Radioactive Materials

An MRE that relates an EA's effectiveness in addressing conditions that could produce larger releases from the repository is determined by comparing the 95th percentiles of the cumulative distributions results of the 1,000 random sample calculations for quantities of radioactive materials transported in reference to the EA and the baseline. In this case, the individual sample calculations are not directly correlated. The objective is to gain confidence that an EA may reduce the quantities of radioactive materials that could potentially be released under combinations of physical conditions particularly favorable for transport.

3.2.3 Assumptions and Input for Factor 2

3.2.3.1 Assumptions

The calculations conducted for evaluation of an EA assume that an intrusion event corresponding to the E1, E2, or E1E2 scenarios has occurred. The calculations do not address the frequency at which these intrusion events occur. They calculate only the consequences of a breach of repository containment as produced by the intrusion event.

Numerical model uncertainty is related to the inability to incorporate the actual physical complexity of the process into the model analysis. Factor 2 analysis assumes that no uncertainty is attributable to the computer models used. This assures that any uncertainty in modeling would impact both the performance of the baseline design and the EA in a similar manner, and thus not have a significant impact on the calculation of MREs.

3.2.3.2 Input Parameter Distributions

The distributions used for the uncertainty analysis were derived by interpretation of the evidence used to establish the point estimates for Factor 1. Only a limited amount of information was available regarding the uncertainty, mostly in the form of upper and lower bounds. Consequently, the uncertainty distributions were formulated using the combined judgement of both the Factor 1 and Factor 2 teams to best reflect the available evidence. Table 3-4 identifies the baseline physical parameters whose uncertainty has been judged to have a potential significant influence

TABLE 3-4

DEFINITION OF UNCERTAIN PARAMETERS IN THE DESIGN ANALYSIS MODEL

Parameters Having Uncertainty	Variable Description (units)	Is this Variable Changed by an Engineered Alternative?															
		1	6	10	33	35a,b	77a	77b	77c	77d	83	94a	94b	94c,d	94e	94f	111
BHUMRATE	Microbial gas generation rate under humid facility conditions (moles/kg cellulosics-yr)	No Change From Baseline															
BINURATE	Microbial gas generation rate from anoxic corrosion under inundated facility conditions (moles/kg cellulosics-yr)	No Change From Baseline															
BIOSTOIC	Ratio of moles of biogas generated to moles of cellulosics consumed (dimensionless)	No Change From Baseline															
CB	Brine inflow rate at a pressure difference of lithostatic minus atmospheric (m3/yr-panel)	No Change From Baseline															
H2MAX	Maximum hydrogen gas generation potential from anoxic corrosion (mol/panel)	Yes	Yes	Yes	No Change		Yes	Yes	Yes	Yes	No Change From Baseline						
HHUMRATE	Hydrogen gas generation rate from anoxic corrosion under humid facility conditions (moles/drum-yr)	No Change From Baseline															
HINURATE	Hydrogen gas generation rate from anoxic corrosion under inundated facility conditions (moles/drum-yr)	No Change From Baseline															
KPANH	Negative log of the permeability of the anhydrite beds (dimensionless)	No Change from Baseline															
RADFAC	Factor used to estimate the effective borehole radius during intrusion (dimensionless)	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
RADSOL (1)	Pu-240 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (2)	U-236 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (3)	Am-241 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (4)	Np-237 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (5)	U-233 solubility in brine (mol/l)	Completely Correlated With RADSOL(2)															
RADSOL (6)	Th-229 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (7)	Pu-238 solubility in brine (mol/l)	Completely Correlated With RADSOL(1)															
RADSOL (8)	U-234 solubility in brine (mol/l)	Completely Correlated With RADSOL(2)															
RADSOL (9)	Th-230 solubility in brine (mol/l)	Completely Correlated With RADSOL(6)															
RADSOL (12)	Pu-239 solubility in brine (mol/l)	Completely Correlated With RADSOL(1)															
RBOR	Radius of borehole for intrusion scenarios (m)	No Change From Baseline															
RHTORW	Ratio of hydrogen gas generation rate to water consumption rate during anoxic corrosion (dimensionless)	No Change From Baseline															

on the assurance of compliance. Detailed documentation of the input parameter distributions can be found in Appendix J.

Dependencies and correlations among input parameters are modeled using the STADIC sampling subroutine by allowing the same random number to be used to generate the values for two or more physical parameters. Details of the specific variables for which dependencies are established are given in Appendix J. For example, they include dependencies between the inundated and humid gas generation rates for both anoxic and biodegradation conditions. The dependency reflects the similarity of the chemical conversion involved, with the differences in brine availability producing a different model for the rate of the process and reflects the judgement that the humid gas generation rate should never exceed the inundated gas generation rate, since the cumulative distribution of the humid process has lower values at all percentiles of the distribution.

3.2.4 Results of Analysis of Factor 2

The results of the uncertainty analysis are presented in a series of four tables that match the MREs for releases to both the surface and the Culebra assuming the three human intrusion scenarios, as defined in Section 3.2.2. The description of the variability within the 1,000 case-by-case calculations of the overall MRE is broken into three parts:

- The first column shows the percentage of cases that produced no transport of radioactive material from the repository. These cases reflect the combination of parameters values that produce conditions favorable for complete containment.

- The next four columns present the 5th, 50th (median) and 95th percentile distribution parameters and the mean value of the distribution of MRE for those cases that do not include zero transport in either the baseline design or the engineered alternatives. The percentage of cases that produce no transport can be read directly from the first column. Of this percentage, the cases that were zero for the baseline are indeterminate, with the remaining having an MRE of zero.

- The sixth column presents the percentage of cases that produced the same upper bound value of release. These cases reflect the combination of parameter values that produce conditions favorable for transport.

The last column of the table presents the MRE comparing the 95th percentiles of the CCDF of predicted cumulative release of radioactive materials released for each engineered alternative. This MRE is a single point value.

3.2.4.1 Release of Cuttings, All Scenarios

By definition, all baseline and EA calculations for the drill cuttings release scenario resulted in the release of radioactive material to the surface in the cuttings, since the material intersected by the borehole must be deposited on the surface. None of the EAs that passed the screening process change the horizontal footprint of waste that the drilling operation could intersect. Therefore, the major impact of an EA with respect to radionuclide releases is the reduction in the effective radius of the borehole due to the increased effective resistance of the waste material to erosion during the drilling process.

Table 3-5 shows the results of the uncertainty calculations for cuttings release by all scenarios. First, it can be seen that radioactive materials removed from the repository horizon with drill cuttings is not subject to lower or upper bounds. This is reasonable, since the drilling operation must pass through only a few meters of waste at most, with compaction making the layer thinner. Given even conservatively slow drilling rates, the borehole walls should not be subject to slurry erosion from the drilling process for more than a few hours. Thus, the enlargement of the borehole radius due to erosion of waste is expected to be between a Factor 1 and 3, as indicated in Table J-4 of Appendix J. Thus, the MRE predicted by the DAM for reduction in cuttings removal can vary at most by a factor of 9 across all alternatives, with each MRE being well defined.

Figures 3-2 and 3-3 illustrate the results given in Table 3-5 for ease of comparison. It can be seen from these figures that plasma processing produces the best MRE for reducing cuttings releases. In fact, the waste composite produced by plasma processing produces an approximate maximum possible improvement, because it is estimated that waste treated by plasma processing could make the effective radius of the eroded borehole very close to that of the drill bit. There are no other significant trends among the other alternatives.

3.2.4.2 Waterborne Transport, Scenario E1

Table 3-6 gives the results for waterborne transport of radioactive materials from the repository to the Culebra (Scenario E1). For all 1,000 trials the transported quantities of radionuclides fell in a narrow band of values, indicating that the processes modeled in the DAM may not be sensitive to the input parameters that were modeled with uncertainty. This result can be explained by the boundary conditions imposed upon the repository by the assumptions made about the Castile. In Scenario E1, a borehole completely penetrates the Salado salt formation and punctures the Castile approximately 656 feet (200 meters) below the level of the repository. The Castile is assumed to contain a brine reservoir that is an infinite source of salt-saturated fluid at high pressure, resulting in a continuous flow of brine up the borehole to the Culebra.

As the brine flows through the repository level via the borehole, it may also spread into a limited volume of the waste composite, termed the wash-through volume. As it passes through the waste composite, it dissolves radionuclides to the limit of their solubilities in brine. As indicated in Appendix E, the quantities of radionuclides transported to the Culebra as a result of E1 is a function of the quantity of water flowing from the Castile and the volume of the repository it washes through. If a sufficient quantity of this brine flows through some volume of the repository, radioactive material will be carried to the Culebra until the available inventory of radionuclides in the wash-through volume is completely depleted. The calculated results of the 1,000 uncertainty cases are insensitive to the solubility of radionuclides in brine, indicating that the 5,000 years available after the intrusion event is sufficient to produce this result. Consequently, transport of radioactive material to the Culebra in this scenario is primarily dependent on the magnitude of the wash-through volume and the radionuclide inventory within that volume.

An important parameter for determining both the rate of brine flow through the repository and the size of the wash-through volume is the hydraulic conductivity of the backfill/waste composite. Hydraulic conductivity of the backfill/waste composite is not derived by the DAM and is currently expressed as a ninth order polynomial of the effective stress level of waste compaction (Appendix F). Since specifying the uncertainty of the hydraulic conductivity correlation would require establishing a weighted set of polynomial expressions, each with its own set of nine

TABLE 3-5

UNCERTAINTY ANALYSIS OF MEASURE OF RELATIVE EFFECTIVENESS FOR RELEASE OF CUTTINGS TO THE SURFACE (ALL SCENARIOS)

TRU Disposal System Scenario					Variability in Case by Case Calculations of MRE						MRE for 95th %-tiles of EA & Baseline Transport CCDFs
						Distribution of MREs for Cases With No Zero Transport					
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Percent Runs Producing Zero Transport	5th Percentile (most benefit)	Median	Mean	95th Percentile (least benefit)	Percent Runs at Maximum Limit of Transport	
	None	None	1	Baseline	0%					0%	N/A
		Sand+Clay	2	33	0%	0.91	0.92	0.92	0.92	0%	0.92
		SAG	3	35a	0%	0.40	0.40	0.40	0.40	0%	0.40
		CG	4	35b	0%	0.40	0.40	0.40	0.40	0%	0.40
		Clay	5	111	0%	0.93	0.94	0.94	0.94	0%	0.94
		CaO + Salt	6	83	0%	0.94	0.94	0.94	0.94	0%	0.94
	Super C	None	7	1	0%	0.25	0.26	0.26	0.26	0%	0.25
		SAG	8	77a	0%	0.21	0.21	0.21	0.21	0%	0.21
		Clay	9	77b	0%	0.21	0.21	0.21	0.22	0%	0.21
		Sand+Clay	10	77c	0%	0.21	0.21	0.21	0.21	0%	0.21
		CaO + Salt	11	77d	0%	0.21	0.21	0.21	0.22	0%	0.22
	S&C	None	12	6	0%	0.75	0.79	0.78	0.80	0%	0.77
	SCC	None	13	94a	0%	0.56	0.57	0.57	0.57	0%	0.57
		Sand+Clay	14	94b	0%	0.52	0.52	0.52	0.52	0%	0.52
		CG	15	94c	0%	0.29	0.30	0.30	0.30	0%	0.30
		SAG	16	94d	0%	0.29	0.30	0.30	0.30	0%	0.30
		Clay	17	94e	0%	0.53	0.53	0.53	0.53	0%	0.53
		CaO + Salt	18	94f	0%	0.53	0.54	0.53	0.54	0%	0.54
	Plasma	None	19	10	0%	0.11	0.12	0.13	0.18	0%	0.12

LEGEND:
Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
EC/SC: Enhanced cementation of sludges. Shred and add clay based materials to organics and inorganics
SAG: Salt aggregate grout
CG: Cementitious grout

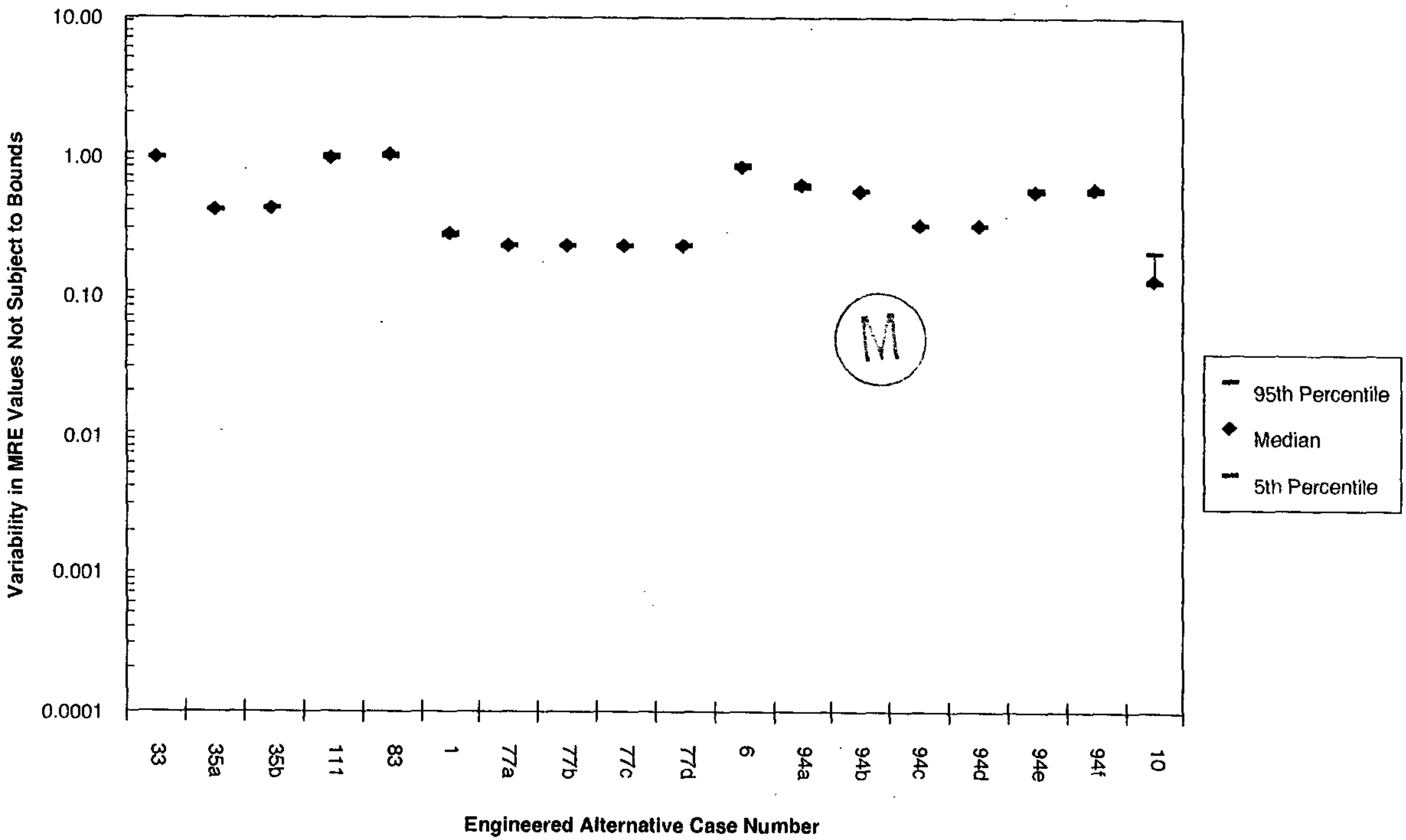


Figure 3-2

Uncertainty Analysis of Case-by Case Measure of Relative Effectiveness for Release of Cuttings to the Surface (all scenarios)

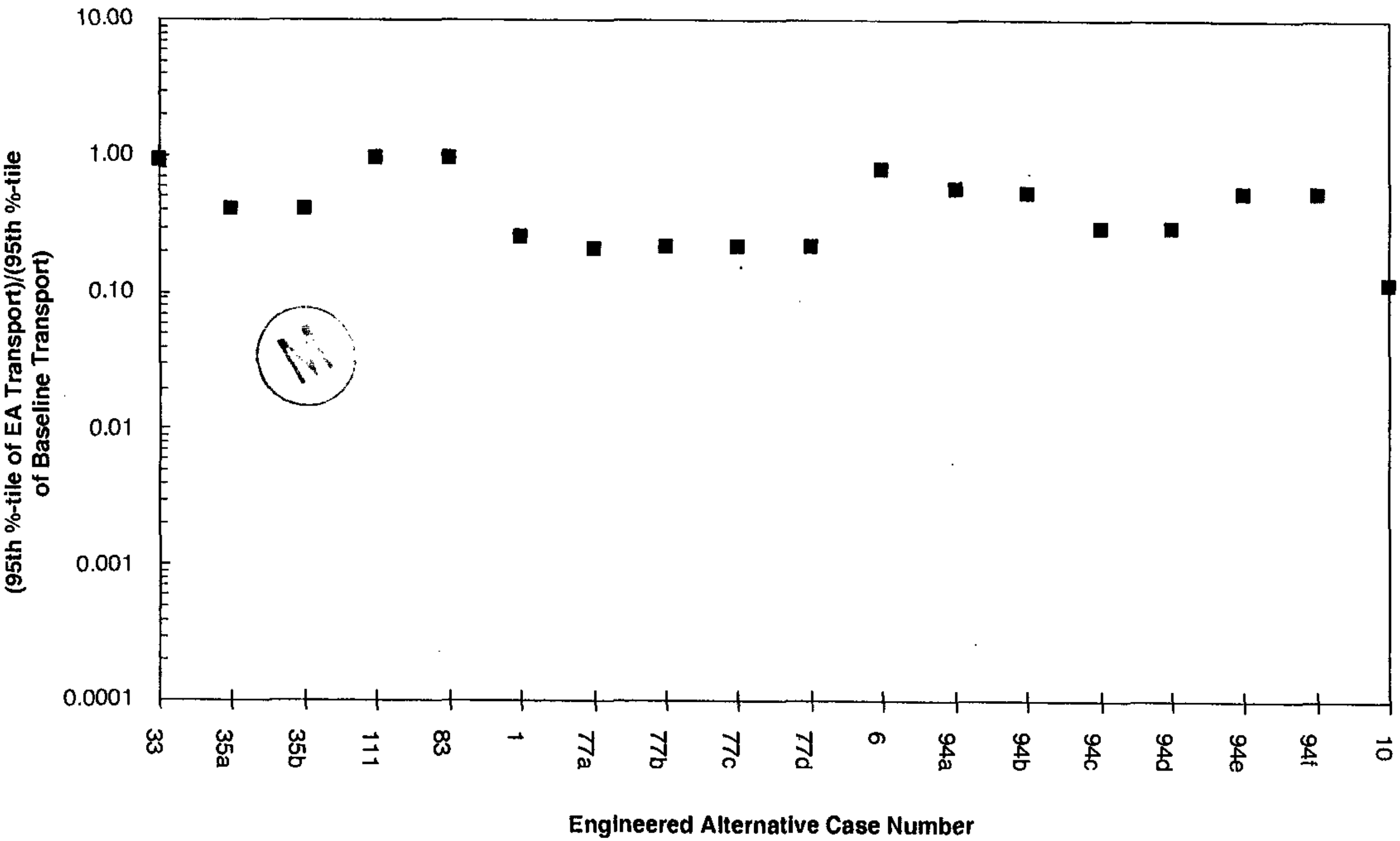


Figure 3-3

Measure of Relative Effectiveness for Reducing 95th Percentile of All Uncertainty Case Runs for Release of Cuttir~~ to the Surface (all scenarios)

TABLE 3-6

UNCERTAINTY ANALYSIS OF MEASURE OF RELATIVE EFFECTIVENESS FOR WATERBORNE TRANSPORT TO CULEBRA DOLOMITE (SCENARIO E1)

TRU Disposal System Scenario					Variability in Case by Case Calculations of MRE						
						Distribution of MREs for Cases With No Zero Transport					
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Percent Runs Producing Zero Transport	5th Percentile (most benefit)	Median	Mean	95th Percentile (least benefit)	Percent Runs at Maximum Limit of Transport	MRE for 95th %-tiles of EA & Baseline Transport CCDFs
	None	None	1	Baseline	0%					0%	N/A
		Sand+Clay	2	33	0%	0.73	0.75	0.75	0.78	0%	0.73
		SAG	3	35a	0%	0.40	0.41	0.41	0.42	0%	0.40
		CG	4	35b	0%	0.40	0.41	0.41	0.42	0%	0.40
		Clay	5	111	0%	0.53	0.54	0.54	0.55	0%	0.53
		CaO + Salt	6	83	0%	0.83	0.83	0.81	0.84	0%	0.83
	Super C	None	7	1	0%	0.92	0.93	0.93	0.94	0%	0.94
		SAG	8	77a	0%	0.43	0.45	0.45	0.47	0%	0.43
		Clay	9	77b	0%	0.55	0.56	0.57	0.59	0%	0.55
		Sand+Clay	10	77c	0%	0.72	0.74	0.74	0.78	0%	0.72
		CaO + Salt	11	77d	0%	0.60	0.80	0.77	0.81	0%	0.78
	S&C	None	12	6	0%	0.92	0.94	0.94	0.96	0%	0.96
	SCC	None	13	94a	0%	0.68	0.69	0.70	0.72	0%	0.68
		Sand+Clay	14	94b	0%	0.64	0.66	0.66	0.69	0%	0.64
		CG	15	94c	0%	0.44	0.45	0.45	0.47	0%	0.44
		SAG	16	94d	0%	0.44	0.45	0.45	0.47	0%	0.44
		Clay	17	94e	0%	0.52	0.54	0.54	0.56	0%	0.52
		CaO + Salt	18	94f	0%	0.26	0.67	0.63	0.68	0%	0.66
	Plasma	None	19	10	0%	0.0004	0.0007	0.0008	0.0012	0%	0.0011

LEGEND:
Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
EC/SC: Enhanced cementation of sludges. Shred and add clay based materials to organics and inorganics
SAG: Salt aggregate grout
CG: Cementitious grout

coefficients, to express the range of potential relations, only a best estimate was used for EA comparison purposes. This explains the very narrow range of actinide activity transported and also the resultant overall MRE.

Figures 3-4a and 3-4b plot the results given in Table 3-6 for ease of comparison. It can be seen from this figure that plasma processing reduces transport following an E1 scenario by a factor of over 1,000, whereas all the other alternatives produce reductions of less than a factor of 10. This significant difference is attributed to the resulting very low hydraulic conductivity within the waste horizon for a vitrified waste/salt composite. This very low permeability greatly restricts the radius to which the wash-through volume extends into the waste horizon, compared to the baseline design and all other alternatives.

Of those involving backfill, the engineered alternatives that use either SAG or SG backfill provide the best performance for the E1 Scenario. These backfill options would tend to provide a consistently tough waste composite across the entire cross section penetrated by the borehole.

3.2.4.3 Waterborne Transport, Scenario E2

Of all the scenarios and mechanisms for transport investigated in this study, waterborne transport as a result of the E2 Scenario is the most dependent on the inflow of brine and the buildup of fluid pressure within the undisturbed repository. It does not have the assumed pressure and infinite source of brine available from the Castile as a driving force to move radionuclides to the Culebra, as is the case with the E1 scenario.

Because of the wide variation in the physical input parameters, there are random sample calculations in which the baseline design for the EA may produce waterborne radioactive transport to the Culebra of zero. For example, a combination of conditions that produce a low repository pressure may result in a hydraulic head too low for water to rise to the Culebra. In addition, low brine inflow and/or a high brine consumption rate from anoxic corrosion may simply not provide sufficient brine for any release. Conversely, there are a group of random sample calculations in which the baseline design or the EA produce waterborne radioactive transport to the Culebra at a bounding limit corresponding to the entire inventory of radioactive material available in a panel.

Table 3-7 shows that about 1 percent of cases for the baseline design produce zero releases, while 7% of the cases transport essentially all available radionuclides in a panel. Many of the EAs increase the percentage of cases that produce zero transport, but some also increase the number of cases that produce releases at the upper limit of waste that is available for hydraulic communication with the borehole. It should be noted that plasma processing produces the most improvement by far and also produces the least spread of MRE values. This indicates that the vitrified waste/salt composite has performance properties that are insensitive to the quantities that were modeled with uncertainty for this analysis.

Figures 3-5a and b plot the results given in Table 3-7 for ease of comparison. As with Scenario E1, plasma processing produces the most improvement of performance against E2 scenarios, for the same reason as stated in Section 3.2.4.3 for E1 scenarios. The backfill EAs that use lime (CaO) to reduce the actinide solubility also produces a very significant benefit because the limited availability of brine enhances the importance of actinide solubility. The SAG and CG backfill also add some benefit, although not as significant as lime. The waste processing options have little to no significant impact on performance. In Figure 3-5b, the large number of

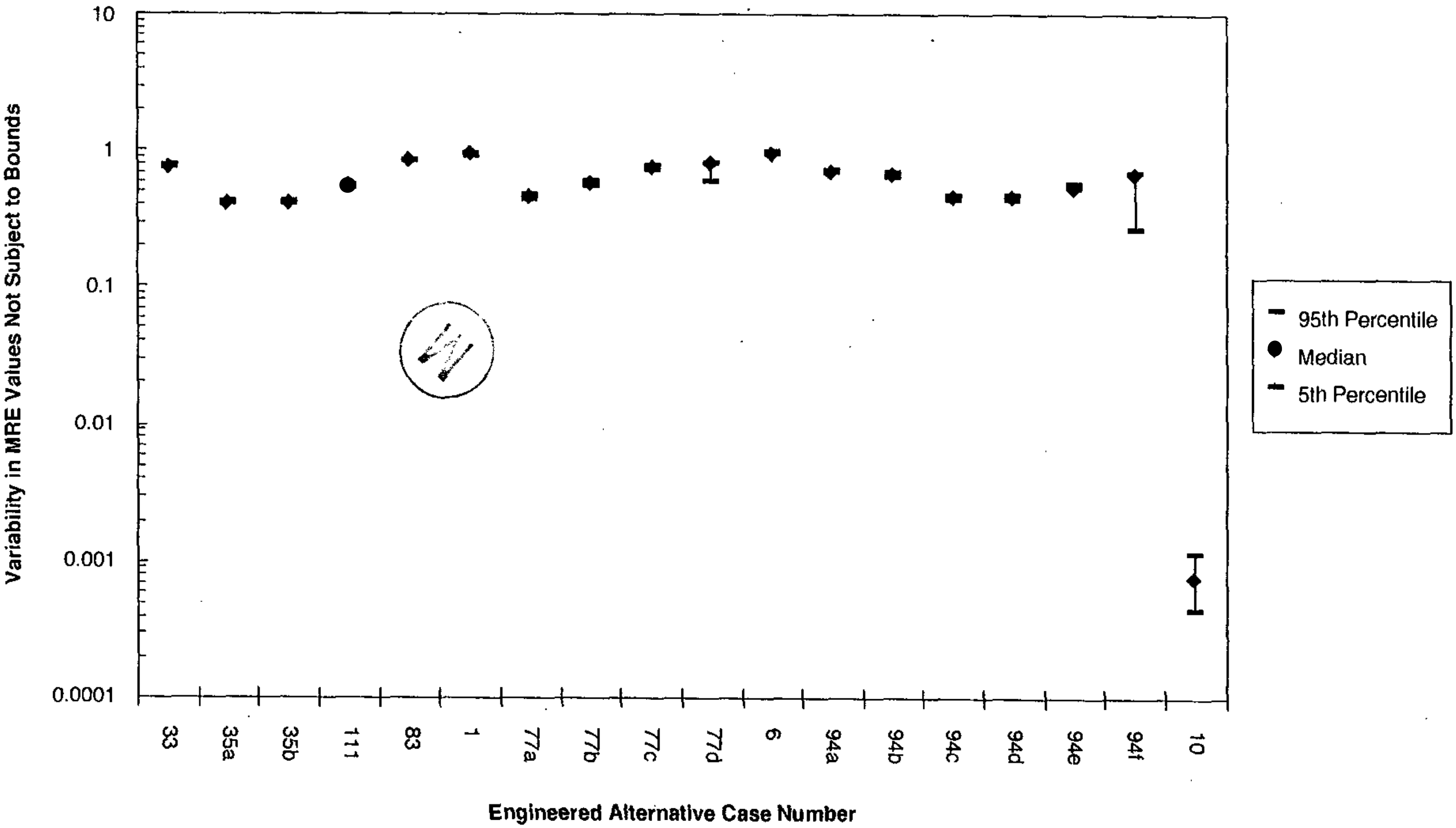


Figure 3-4a

Uncertainty Analysis of Case-by Case Measure of Relative Effectiveness for Waterborne Transport to Culebra Dolomite (Scenario E1)

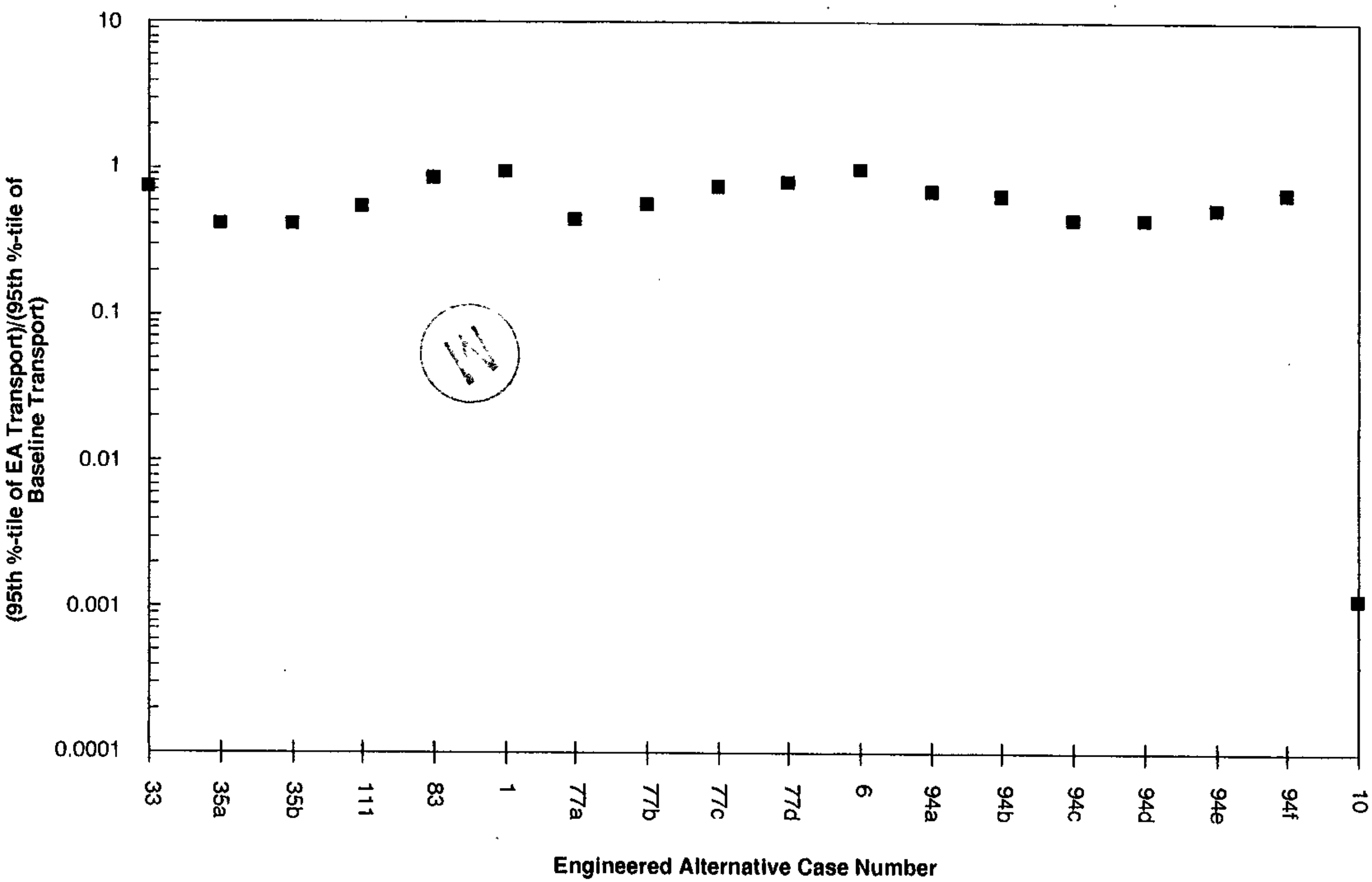


Figure 3-4b

Measure fo Relative Effectiveness for Reducing 95th Percentile of All Uncertainty Case Runs for Waterborne Transport to Culebra Dolomite (Scenario E1)

76435.01.00.00/zc A114

TABLE 3-7

UNCERTAINTY ANALYSIS OF MEASURE OF RELATIVE EFFECTIVENESS FOR WATERBORNE TRANSPORT TO CULEBRA DOLOMITE (SCENARIO E2)

TRU Disposal System Scenario					Variability in Case by Case Calculations of MRE						
						Distribution of MREs for Cases With No Zero Transport					
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Percent Runs Producing Zero Transport	5th Percentile (most benefit)	Median	Mean	95th Percentile (least benefit	Percent Runs at Maximum Limit of Transport	MRE for 95th %-tiles of EA & Baseline Transport CCDFs
	None	None	1	Baseline	1%					7%	N/A
		Sand+Clay	2	33	21%	0.31	1.07	1.11	1.99	7%	1.00
		SAG	3	35a	24%	0.18	0.71	0.68	1.09	3%	0.54
		CG	4	35b	24%	0.18	0.71	0.68	1.09	3%	0.54
		Clay	5	111	21%	0.33	1.14	1.20	2.18	7%	1.00
		CaO + Salt	6	83	7%	0.009	0.12	0.24	0.84	0%	0.009
	Super C	None	7	1	0%	0.61	1.08	1.28	2.08	8%	1.00
		SAG	8	77a	19%	0.091	0.31	0.37	0.87	1%	0.19
		Clay	9	77b	18%	0.45	1.11	1.23	2.35	8%	1.00
		Sand+Clay	10	77c	18%	0.37	1.06	1.15	2.06	8%	1.00
		CaO + Salt	11	77d	4%	0.009	0.119	0.235	0.83	0%	0.009
	S&C	None	12	6	0%	0.75	1.01	1.17	1.75	8%	1.00
	SCC	None	13	94a	24%	0.19	0.72	0.69	1.08	3%	0.57
		Sand+Clay	14	94b	56%	0.14	0.74	0.77	1.61	2%	0.25
		CG	15	94c	59%	0.03	0.37	0.41	0.88	1%	0.08
		SAG	16	94d	59%	0.03	0.37	0.41	0.88	1%	0.08
		Clay	17	94e	55%	0.16	0.75	0.78	1.62	2%	0.26
		CaO + Salt	18	94f	31%	0.005	0.09	0.19	0.75	0%	0.009
	Plasma	None	19	10	0%	0.0009	0.0088	0.0194	0.0549	0%	0.0018

LEGEND:
Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
EC/SC: Enhanced cementation of sludges. Shred and add clay based materials to organics and inorganics
SAG: Salt aggregate grout
CG: Cementitious grout

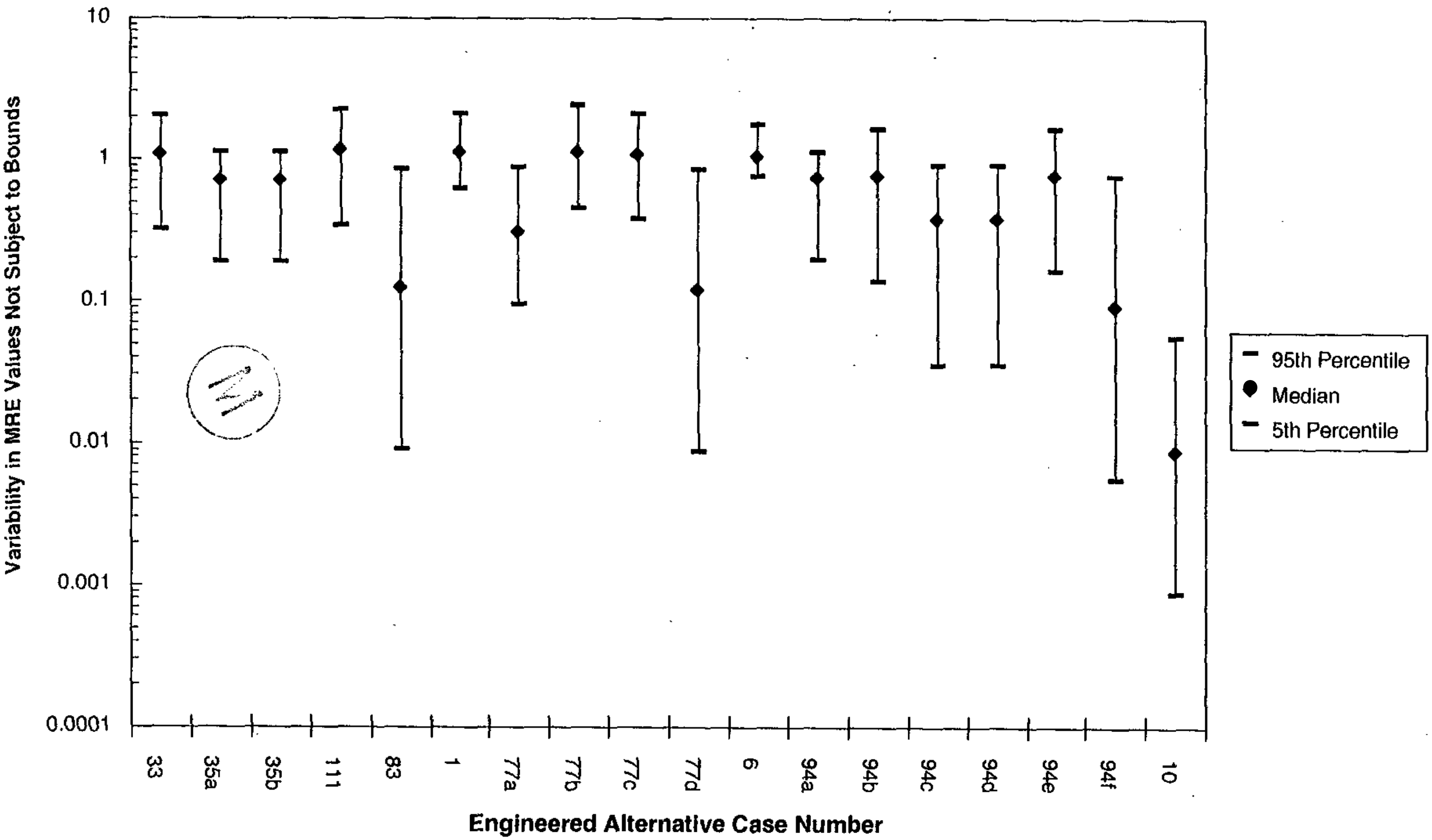


Figure 3-5a

Uncertainty Analysis of Case-by Case Measure of Relative Effectiveness for Waterborne Transport to Culebra Dolomite (Scenario E2)

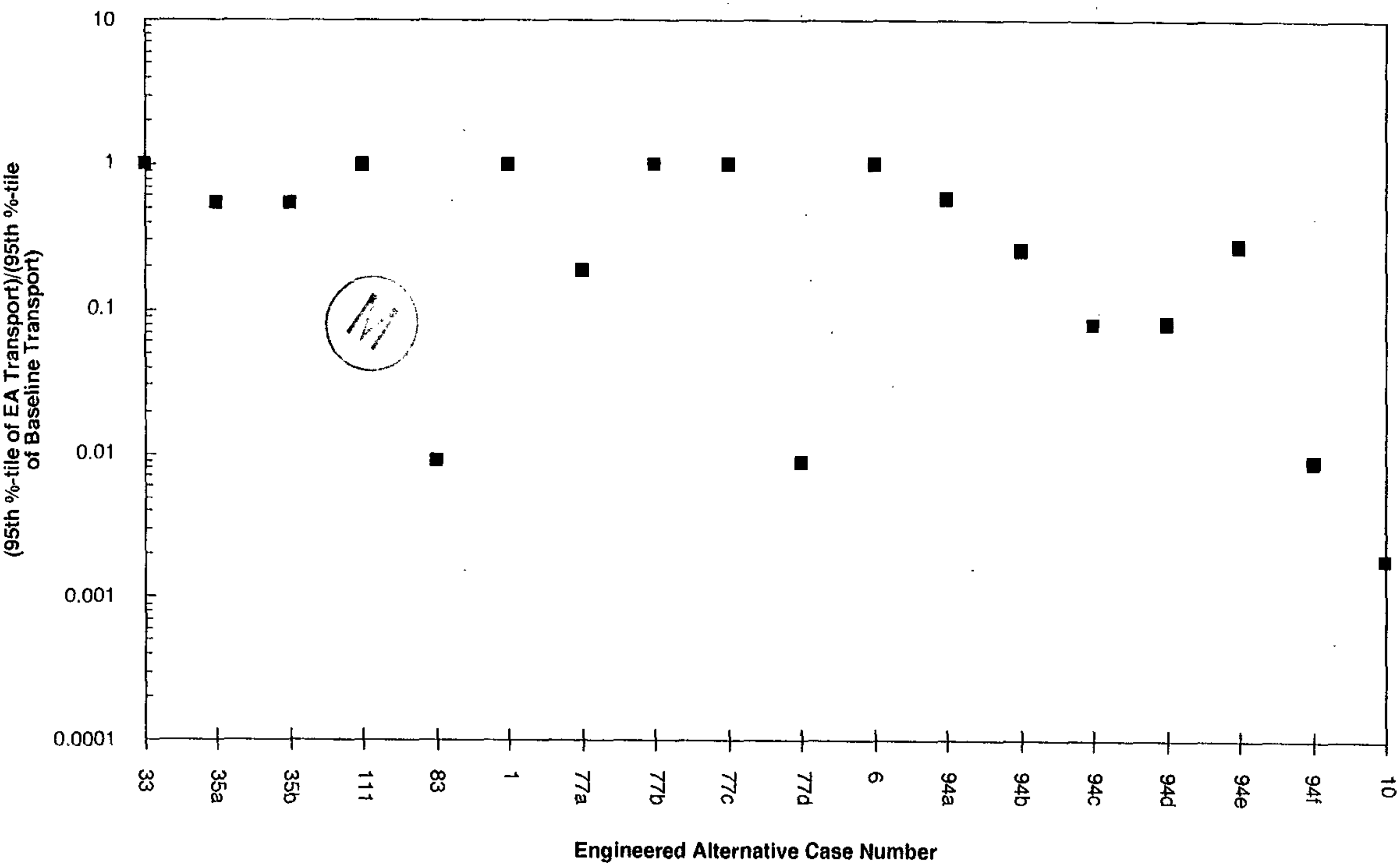


Figure 3-5b

Measure of Relative Effectiveness for Reducing 95th Percentile of All Uncertainty Waterborne Transport to Culebra Dolomite (Scenario E2)

values at 1.0 indicate that at least 5% of the cases are producing releases at the limit of available radionuclide inventory for both the baseline design and the EA. In these cases, the EA has no impact on the potential for the larger releases for this scenario.

3.2.4.4 Waterborne Transport, Scenario E1E2

The physical process of interest for the E1E2 Scenario involves saturated brine flowing through the repository horizon between two boreholes. One borehole permits Castile brine at high pressure to flow into the repository, but blocks the brine's path to the surface via that borehole. A second borehole then forms a path for flow in response to the pressure head to the Culebra. For comparison of EA performance, the two boreholes are assumed to be at opposite ends of a room, resulting in the wash-through volume being equal to the volume of one room at the time of the human intrusion event.

As with the E1 Scenario, the quantity of brine that flows through the room is dependent on the backfill/waste composite hydraulic conductivity; but if enough brine flows through the room, the radionuclide inventory in the room can be completely dissolved. Because of the hydraulic conductivity of the baseline design, high pressure, and unlimited supply of brine assumed to be available from the Castile, all the baseline calculations resulted in complete dissolution of the waste inventory of the room. The 1,000 random sample calculations for the E1E2 scenario for the baseline design all result in the same quantity of radionuclide transport.

Table 3-8 and Figure 3-6a and 3-6b show the results for waterborne transport due to the E1E2 Scenario. The EAs that are effective against Scenario E1E2 either alter the backfill/waste composite hydraulic conductivity or the actinide solubility along that path, which is assumed to consist of an entire room. Consistent with E1 and E2, plasma processing, which produces the greatest reductions in permeability, results in the best improvement. However, other EAs also produced good results. Those EAs that use either SAG or CG backfill significantly reduce permeability, which in turn reduces the backfill/waste composite hydraulic conductivity. This lowers the rate of brine flow, thus reducing the quantity of brine available to dissolve and transport actinides. The EAs that employ lime reduce solubility, thus lowering the quantity of actinides that a given amount of brine can dissolve.

TABLE 3-8

UNCERTAINTY ANALYSIS OF MEASURE OF RELATIVE EFFECTIVENESS FOR WATERBORNE TRANSPORT TO CULEBRA DOLOMITE (SCENARIO E1E2)

TRU Disposal System Scenario					Variability in Case by Case Calculations of MRE						
						Distribution of MREs for Cases With No Zero Transport					
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Percent Runs Producing Zero Transport	5th Percentile	Median	Mean	95th Percentile	Percent Runs at Maximum Limit of Transport	MRE for 95th %-tiles of EA & Baseline Transport CCDFs
	None	None	1	Baseline	0%					100%	N/A
		Sand+Clay	2	33	0%	0.99	0.99	0.97	0.99	96%	0.99
		SAG	3	35a	0%	0.009	0.036	0.129	0.75	4%	0.75
		CG	4	35b	0%	0.009	0.036	0.129	0.75	4%	0.75
		Clay	5	111	0%	0.024	0.476	0.53	0.99	35%	0.99
		CaO	6	83	0%	0.012	0.041	0.14	0.76	4%	0.76
	Super C	None	7	1	0%	1.00	1.00	1.00	1.00	100%	1.00
		SAG	8	77a	0%	0.011	0.075	0.224	0.98	10%	0.98
		Clay	9	77b	0%	0.037	0.825	0.63	0.98	48%	0.98
		Sand+Clay	10	77c	0%	0.98	0.98	0.96	0.98	96%	0.98
		CaO	11	77d	0%	0.012	0.027	0.094	0.438	2%	0.437
	S&C	None	12	6	0%	1.00	1.00	1.00	1.00	100%	1.00
	SCC	None	13	94a	0%	0.37	1.00	0.93	1.00	88%	1.00
		Sand+Clay	14	94b	0%	0.22	0.99	0.89	0.99	82%	0.99
		CG	15	94c	0%	0.01	0.08	0.23	0.98	11%	0.98
		SAG	16	94d	0%	0.01	0.08	0.23	0.98	11%	0.98
		Clay	17	94e	0%	0.024	0.44	0.52	0.99	34%	0.98
		CaO	18	94f	0%	0.009	0.012	0.020	0.045	1%	0.045
	Plasma	None	19	10	0%	0.0003	0.0009	0.0018	0.0066	0%	0.01

LEGEND:
Super C: Shredding and compaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
SAG: Salt Aggregate Grout
CG: Cementitious Grout

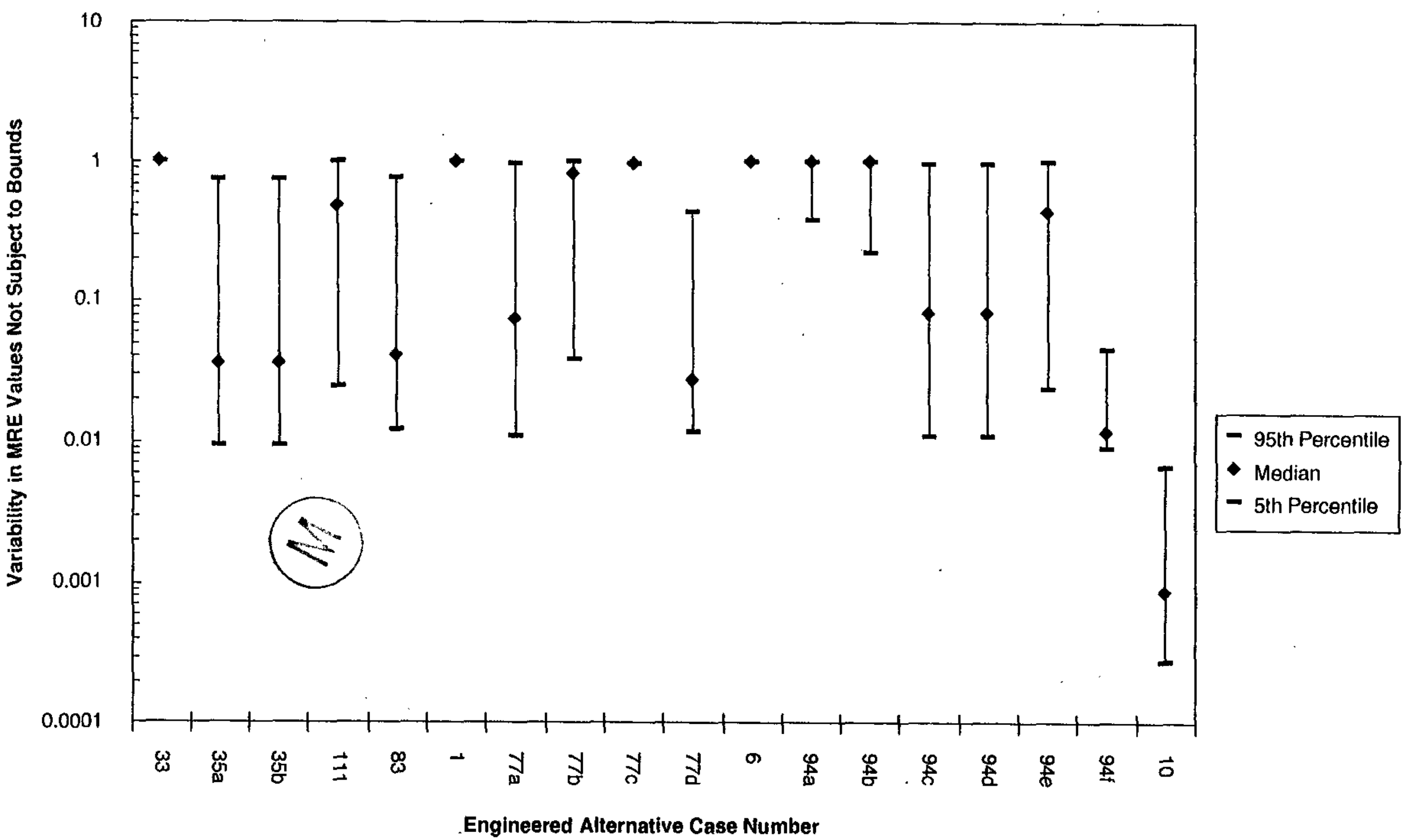


Figure 3-6a

Uncertainty Analysis of Case-by-Case Measure of Relative Effectiveness for Waterbourne Transport to Culebra Dolomite (Scenario E1E2)

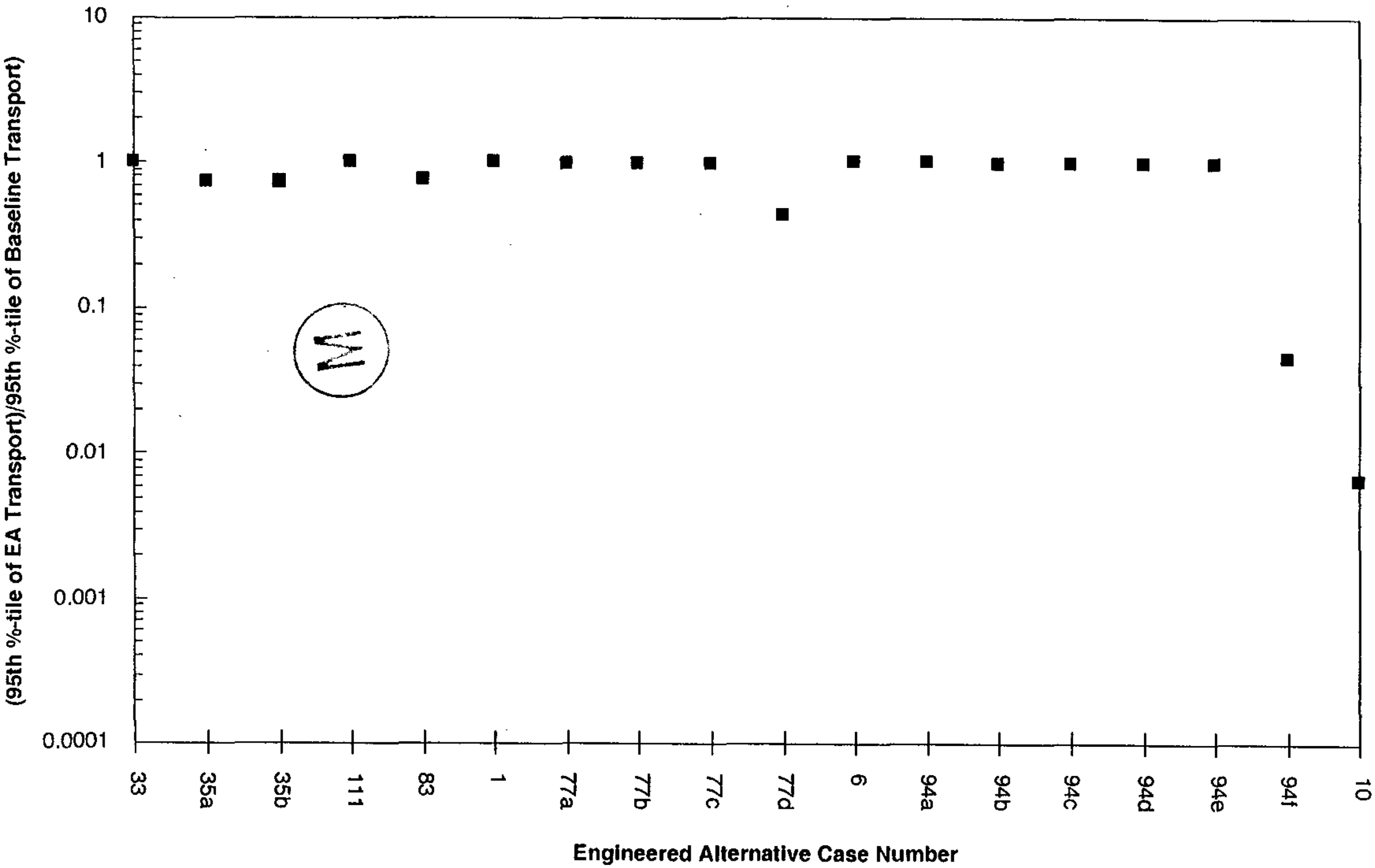


Figure 3-6b

Measure of Relative Effectiveness for Reducing 95th Percentile of All Uncertainty Waterborne Transport to Culebra Dolomite (Scenario E1E2)

3.3 FACTOR 3: IMPACT ON WORKER AND PUBLIC RISK

3.3.1 Definition of Factor 3

Discussion of the human health risks associated with adopting an EA includes impacts that may be realized at the WIPP site and generator or disposal facilities that are involved with TRU or TRU-mixed waste. Consideration of potential impacts includes radiation effects (both radiation emanating from waste or processing equipment and the release of radioactive material), effects from the release of hazardous material, and, in the case of individuals within the facilities, ordinary industrial hazards. Impacts are considered for the following five groups of individuals at the WIPP and at the generator/disposal sites:

- Workers directly involved with handling, processing, or storing TRU waste (generally referred to as "workers")
- Other workers in the facility who are not directly involved with the TRU waste (also referred to as "co-located workers")
- The co-located worker who receives the highest exposure to radiation or hazardous material from TRU waste activities
- All members of the public who live within 50 miles (80.5 km) of the facility where the TRU waste is being handled, processed, or stored (generally referred to as "public")
- The member of the public located off-site who receives the highest exposure from activities associated with TRU handling, processing, or disposal (often called the Maximum Off-Site Individual or MOI).

Radiation emanating from waste or processing equipment primarily affects workers. Because co-located workers and members of the public are much further from the source of radiation, the human health impacts on these groups are small and can be ignored in this analysis. Hazardous and toxic chemicals do not have human health impacts on any of the groups as long as the chemicals remain contained.

If radioactive material, hazardous material, or toxic chemicals do not remain contained within packaging, they may pose a hazard to workers, co-located workers, or the public, primarily by being taken into the body via numerous exposure processes. Such releases may result from faulty packaging, violation of the integrity of the packaging, or opening of the packaging during processing. To constitute a risk, however, the released materials must come in contact with an individual. To do that, the material must move through some pathway between the source of material and the exposed individual. The most frequent pathway involves some portion of the material becoming airborne, moving in air to the exposed individual, and being inhaled. Other pathways include contamination of water that is subsequently consumed by the exposed individual or used to water food crops or provide drinking water for animals; deposition from the air to food crops; and deposition on the ground where it may be taken up by plants, become a source for contaminating water, or be resuspended in the air. Exposure may also come from contact with or ingestion of soil or other materials contaminated by the waste.

Human health impacts are not generally measured the same way for radiation, toxic chemicals, carcinogenic chemicals, or industrial accidents. To facilitate comparison with other reported data, this document reports impacts in the units most commonly used in other studies. In addition, to the extent possible, the report also displays results in units that will facilitate comparing the impacts from the different types of hazards, recognizing that the endpoints are not identical. The following paragraphs describe significant differences between the endpoints reported.

Standard health and safety control practices include administrative control of exposures to radiation or hazardous material for workers as individuals and as groups. Workers are often rotated through hazardous and nonhazardous work to limit individual exposures. For this reason, the concept of the full-time equivalent (FTE) is used in relation to worker doses. An FTE is assumed to be commensurate to one individual working full time in a waste management facility even though it may actually represent a number of individuals, none of whom work full time in the facility. Rather than reporting maximum individual or average worker doses, the report uses collective dose for all workers. These doses will be expressed in FTE-rem rather than person-rem to emphasize that they are worker and not public doses.

The impacts of exposure to radiation and to carcinogenic chemicals may be reported as excess cancers. Unfortunately, most of the data reported in the literature relating radiation exposure and cancer are given in terms of cancer fatalities, and cancer incidence is usually reported for exposure to carcinogenic chemicals. Because cancer incidence is not synonymous with cancer fatalities, the units for radiation risk will be excess fatalities, and the units for carcinogenic compounds will be excess cancers.

Unlike carcinogenic hazardous chemicals, toxic chemicals do not have an apparent impact when present in less than a threshold concentration. Exposure to these types of chemicals is reported as a fraction of the applicable limit. For members of the public, the estimated long-term air concentration for each chemical is divided by the maximum level to which an individual may be exposed 24 hours a day for 70 years without developing adverse effects. The resulting fraction, called a hazard quotient, is totaled for all reported chemicals and the sum reported as a hazard index. The amount the hazard index exceeds 1.0 can serve as an indicator of relative potential for causing harm.

For workers, the exposure to toxic chemicals is reported as an exposure index. The exposure ratio is calculated similarly to the hazard quotient except that it is based on the maximum concentration that might be observed for each chemical which is divided by a threshold limit value based on safe exposure for a shorter time, typically an 8-hour day or 40-hour week. The sum of the exposure ratios for all chemicals of concern is called the exposure index. An exposure index of greater than 1.0 indicates an increased likelihood of adverse health effects in the workers.

Table 3-9 summarizes the types of human health risk analyses and the units in which the results are reported.

3.3.2 Methodology Used to Evaluate Worker and Public Risk

This section of the report describes the methodology used to produce estimates of worker and public risk. Details of the models and the way they were applied may be found in Appendix K.

TABLE 3-9

REPORTING UNITS FOR HUMAN HEALTH RISK ANALYSIS

Exposure Group	Radiation Impacts	Carcinogenic Chemicals	Toxic Chemicals	Industrial Accidents
Workers (Collective)	FTE-rem Excess Fatalities	Excess Cancers	Exposure Index	Injuries Fatalities
Most Exposed Co-Located Worker	Rem Excess Risk	Excess Cancers	Hazard Index	Not Applicable
Co-Located Workers (Collective)	Person-rem Excess Fatalities	Excess Cancers	Not Applicable	Not Applicable
Most Exposed Off-site Individual	Rem Excess Risk	Excess Cancers	Hazard Index	Not Applicable
Collective Off-site (Public)	Person-rem Excess Fatalities	Excess Cancers	Not Applicable	Not Applicable

Many of the alternatives consist of a combination of a method of waste processing with a method of emplacement of the waste at the WIPP. For the sake of simplicity of presentation and flexibility in considering the impacts of the alternatives, the analysis of the treatment options has been performed separately from the analysis of the impacts of emplacement at the WIPP. With the exception of the data for the maximally exposed individuals, all the human health impacts may be considered additive, and thus, may be considered in multiple combinations.

All alternatives, including the baseline, have some activities in common. Those include retrieval, packaging, and certification of the waste to WIPP WAC standards. All of the alternatives may be considered as various combinations of four waste processes and five emplacement options. The four processing options follow:

- Compact (supercompact) all waste except sludges. This process is included in Alternatives 1 and 77(a–d).
- Shred and compact all waste except sludges, Alternative 6.
- Plasma processing, Alternative 10.
- Shred and add clay-based materials to organics and inorganics used in Alternatives 94(a–f).

The baseline involves no backfill during emplacement. The five emplacement options involve various types of backfill:

- Sand plus clay backfill, Alternatives 33, 77c, and 94b.
- Salt aggregate grout backfill, Alternatives 35a, 77a, and 94d.
- Cementitious grout backfill, Alternatives 35b and 94c.
- Clay-based backfill, Alternatives 77b, 94e, and 111.
- CaO backfill, Alternatives 83, 77d, and 94f.

Table 3-10 displays the processing and emplacement options used in each EA. The total impact of each alternative is the sum of the processing and emplacement impacts.

Because the WIPP is not now active for emplacement of TRU waste, and most of the facilities throughout the DOE system are not operating the types of waste processing specified in the alternatives, all analysis of EA performance must be performed using modeling techniques.

3.3.2.1 Methodology Used to Evaluate Waste Process Impacts

The impacts from each alternative are compared to the impacts from a baseline, which consists of the emplacement of waste certified to meet the WIPP WAC without any backfill of the rooms after emplacement. The baseline includes waste that is already packaged and complies with the WAC, waste that is not yet generated but will be packaged and certified to meet WAC, and waste that is not yet packaged or needs to be repackaged to meet the WAC or that requires some

1 **TABLE 3-10**

HUMAN HEALTH ANALYTICAL COMPONENTS OF EACH ENGINEERED ALTERNATIVE

Engineered Alternative	Processing Analysis	Emplacement Analysis
1	Supercompaction	Same as Baseline
6	Shred and Compact	Same as Baseline
10	Plasma Processing	Same as Baseline
33	Same as Baseline	Sand plus Clay Backfill
35a	Same as Baseline	Salt Aggregate Grout Backfill
35b	Same as Baseline	Cementitious Grout Backfill
111	Same as Baseline	Clay-based Backfill
77a	Supercompaction	Salt Aggregate Grout Backfill
77b	Supercompaction	Clay-based Backfill
77c	Supercompaction	Sand plus Clay Backfill
77d	Supercompaction	CaO Backfill
83	Same as Baseline	CaO Backfill
94a	Shred and Add Clay	Same as Baseline
94b	Shred and Add Clay	Sand plus Clay Backfill
94c	Shred and Add Clay	Cementitious Grout Backfill
94d	Shred and Add Clay	Salt Aggregate Grout Backfill
94e	Shred and Add Clay	Clay-based Backfill
94f	Shred and Add Clay	CaO Backfill

processing to allow certification that it meets the WAC. The latter two situations will require operation of facilities that are considered part of the baseline. These activities are expected to take place at 10 major DOE facilities (see Table 2-4)[1]:

In considering waste processing, where the required waste handling facilities do not currently exist, worker exposures and airborne releases are estimated by assuming a generic facility located at the site. The analysis of these generic facilities is based on individual modules, each of which is designed to perform one specific and necessary part of the task. For example, most generic facilities require a module in which waste is received and inspected and another from which the final product is shipped or sent to a disposal location. Other modules might include repackaging or specific waste processing. Isotopic concentrations of the waste and physical configuration of each module (size and placement of tanks, etc.) are used to estimate worker dose rates. The operations performed in each module are analyzed and estimates of exposure rates, potential air concentrations in the workplace, releases from the vent system, and personnel requirements for operation and maintenance are made and reported on a normalized basis. For example, data on personnel doses are calculated on a per unit throughput basis. Multiplying by the projected annual throughput for a particular site yields an estimate of the annual dose to all the workers for that module. These types of data are then combined for all the necessary modules for a given facility to estimate the annual worker dose for the appropriate waste processing at that particular site. Finally, the data for operations at all waste processing facilities is combined to give a total for the DOE system for that particular alternative.

The impacts of material released to the environment are analyzed independently for each facility. The primary pathway for exposure involves air transport of the material. The impacts associated with the air releases are dependent on local meteorology, air dispersion, and the location of the individual(s) exposed relative to the release point. Thus details of local meteorology and population density and distribution are all inputs to the models for each individual storage or processing facility. In other words, an identical quantity and type of waste going through the same waste processing method may have different human health impacts at each facility.

Performing the analyses as described above involves the application of many very complex models and large data sets. Because performing this type of analysis for all possible combinations of each alternative and each configuration[2] is beyond the scope of this report, a method was developed that simplifies the modeling requirements while retaining adequate information to allow comparison of the many alternatives and configurations. This procedure consists of applying scaling factors to the results of a limited number of the complex analyses described above. The scaling factors are developed independently for each facility and combined to form a weighted scaling factor applied to the systemwide results of the selected fullscale analyses.

[1]Almost all the waste is located at these 10 sites. Minor additional amounts of waste stored at other small DOE sites may be transported to one or more of these sites. These additional amounts of waste are insignificant and do not impact the human health analysis. DOE sites other than these 10 are currently generating small quantities of TRU waste.

[2]Configuration refers to the arrangement of location(s) at which waste processing is assumed to occur. In the 'Distributed' configuration, waste treatment occurs at the ten sites identified previously. In the 'Regional' configuration, waste is transported to five sites for treatment. In the 'Centralized' configuration, all waste is transported to the WIPP and is treated at a facility built for that purpose.

For a selected EA process, there are two primary considerations that would require scaling of human health impacts. One would be whether or not the selected process was performed at the particular facility. The other is the variation in waste throughput at each facility. The difference in throughput at any given facility may result from either changes to meet the WIPP design capacity or modifications in the system-wide configuration. Consider, for example, the Lawrence Livermore National Laboratory (LLNL), which would perform plasma processing of waste in the decentralized configuration but would only be involved in shipping waste to other facilities for the regional and centralized configurations. In addition to these considerations, the amount of waste assumed to be processed and/or shipped from LLNL must be adjusted, along with all other facilities, to match the design capacity of the WIPP.

Changes in process and throughput alter the human health impacts in two primary ways. Human health impacts are primarily due to materials released to the air to which individuals are subsequently exposed and radiation emitted from the waste exposing those in close proximity either to the waste processing equipment or to the waste in disposal. Exposure to radiation or hazardous materials released during transportation activities is considered in Section 3.5, Risk of Transportation. Changes in waste handling during processing and changes in the amount of waste processed change the amount of radioactive and/or hazardous material released to the air. These releases impact co-located workers and the public. Air releases for different waste processes are process-dependent rather than throughput-dependent. For a given waste process, however, the modeled amount of material released is a linear function of the amount of waste processed or the total throughput. Thus, at each facility, modeling must consider each process separately but may apply linear scaling factors to account for variations in waste throughput.

Impacts on workers are primarily time and process dependent for both exposure to radiation and to airborne contaminants in the workplace. The working time is dependent on the processes involved and the amount of waste processed. The variation between processes requires individual analyses for each process or combination of processes. The amount of time workers spend performing a particular waste process, expressed in full-time equivalents or FTEs, is a function of the amount of waste processed or the waste throughput but that function is not a linear function. Efficiencies of scale dictate that, as facility capacities increase, the number of FTEs required to process a given amount of waste decrease, often eventually reaching a point where increases in waste capacity do not increase FTE requirements to perform the activity. These effects may be plotted on graphs showing the number of FTEs required to process a given input capacity. The shape of these graphs depends on not only the process but also the activities within the process and the range of input capacities considered. To facilitate incorporating these data into the modeling, polynomial equations were generated to match the curves for each process considered which included FTE requirements for pre-operational, construction, operation and maintenance (O&M), and decontamination and decommissioning (D&D) activities. Scaling factors for worker impacts were then generated based on the change in the number of FTEs required at each facility for changes in process and throughput. Construction activities and O&M were considered individually since exposure to radiation and air contaminants would not be expected during construction activities.

3.3.2.2 Methodology Used to Evaluate Waste Emplacement and Backfill Impacts

The amount of waste assumed as the input to all treatment processes was based on the amount of waste that would meet the WIPP design limit for the baseline. The output volume for different alternatives varies depending on the processes used to treat the waste. With the exception of alternatives involving plasma processing, scaling factors for the off-site impacts of changing emplacement options are based on the changes in total volume of waste emplaced. The releases of hazardous material from waste treated with the plasma process reflects the expectation that all volatile hazardous material is either destroyed in the plasma process or immobilized in the final waste form.

Although different treatments would produce waste forms that vary in both radioactivity concentration levels and total volume, the potential increase in surface radiation levels is offset by both increased self-shielding and decreased volume of waste handled. The modeling reflects this by retaining a scaling factor of one for worker exposure to all waste forms. Scaling factors for worker impacts, based on changes in the numbers of FTEs for emplacement, are applied only for those alternatives that vary the amount of underground work because of changes in the placement or backfill options. These scaling factors are modeled as linear functions of the number of FTEs because the size of the WIPP facility does not vary in a manner that would affect efficiencies of scale.

The analyses for worker injuries and fatalities are performed by applying statistical data from industry operational experience to the number of affected workers for a particular operation. The operation data that most closely approximates the underground mining activities involved in emplacement and backfilling are those gathered for underground salt mining. Accident statistics are typically represented in terms of incident rates (IR). The incident rate is calculated as the number of occurrences divided by a multiple of the numbers of employee hours worked such as injuries per million person-hours worked. The impacts of accidents are modeled by multiplying the IR by the number of person-hours for the particular activity and alternative. The impacts for above ground waste handling, underground emplacement, and backfill activities are summed to represent the total impact for each alternative.

3.3.3 Assumptions and Input for Factor 3

The DOE Office of Environmental Management is developing extensive analyses of waste processing options at fixed locations for the EMPEIS (DOE, 1994b) consistent with the analytical techniques described in Section 3.3.2. The following alternatives were analyzed for CH-TRU waste:

- No Action (Case 1). CH-TRU waste removal, packaging, certification to WIPP acceptance criteria, and indefinite interim storage at all generator sites.

- Decentralized Alternative (Case 4). CH-TRU waste removal, packaging, certification to WIPP acceptance criteria, and stored at ten installations. CH-TRU waste from smaller sites shipped to one of the ten identified sites for processing and storage.

- Regionalized Alternative (Case 5). CH-TRU waste is consolidated, treated to minimize gas generation, and stored at five installations. Treatment involves shredding of appropriate waste and grouting of all waste.

- Regionalized Alternative 2 (Case 6). CH-TRU waste is consolidated, treated to meet RCRA land disposal restrictions, and stored at five installations. Treatment involves incineration and grouting of ash.

- Regionalized Alternative 3 (Case 8). CH-TRU waste is consolidated, treated to meet RCRA land disposal restrictions, and stored at three installations. Treatment involves incineration and grouting of ash.

- Centralized Alternative (Case 9). CH-TRU waste is consolidated, treated to meet RCRA land disposal restrictions, and disposed of at one installation, the WIPP site. Treatment involves incineration and grouting of ash.

The alternatives analyzed in the EMPEIS are not identical to those selected for analysis by the EACBS, but the similarities are sufficiently close to allow selective use of the EMPEIS results as the basis of the analysis for the four processing options for the alternatives. A discussion of some general observations common to the processing options and a description of the basis for the analysis of each of the processing options follows.

3.3.3.1 General Observations on Processing Options

With the exception of the high temperature treatment of the waste, the processing step with the highest potential for contamination release to the work area and through the facility ventilation and discharge filtration system occurs during opening of waste containers and handling of the waste. This opening and handling of waste is a necessary part of sorting the waste prior to shredding or compacting or grouting organics and inorganics. This tends to make releases from all waste processes that incorporate such activities similar in magnitude for the same throughput of waste. Only those processes that involve high temperatures or other actions that would drive off contaminants in the waste would be expected to show a very significant difference in air releases.

Similarly, except for processes that strongly concentrate the contaminants, the highest dose rates to which workers would be exposed would normally occur when they are handling the waste or waste containers. Manual activities such as emptying and sorting waste from waste containers or waste streams tend to be labor-intensive, leading to increased worker exposures for a given quantity of waste processed.

3.3.3.2 Baseline

The alternative baseline is modeled using the results from the EMPEIS Case 4. Both operations consist of retrieval, packaging, and certification to the WIPP WAC at 10 selected facilities. The modeling accounts for the small amounts of waste shipped from smaller generators to one of the ten processor facilities as well as the increase in throughput required to fill the WIPP to design capacity.

3.3.3.3 Shred and Compact

The alternatives that involve shred and compact of everything but sludges are modeled using the results from the EMPEIS shred and grout process, EMPEIS Case 5. Both waste processing methods involve opening, sorting, and shredding the waste. The compacting and grouting are performed remotely and have similar potential for airborne releases and worker exposures. The releases and exposures for either compacting or grouting are expected to be small compared to opening, sorting, and shredding the waste.

3.3.3.4 Shred and Add Clay-based Materials to Organics and Inorganics

The differences between the addition of grout material to drums of waste, as is done in EMPEIS Case 5, and the addition of clay-based material in the alternatives are negligible both for worker exposures and airborne releases. The shred and add clay EA is modeled after the EMPEIS Case 5 scenario.

3.3.3.5 Supercompaction

The processes used in supercompaction of wastes other than sludges is very similar to shred and compact with the addition of a step following the initial compaction in which the normally compacted drum is compressed in a high pressure hydraulic press. The initial steps do not require shredding but do require opening the waste drums and sorting to assure noncompressible materials are not included in the initial drum loading. Supercompaction is modeled using the results of the EMPEIS shred and grout combined with data on the supercompaction module taken from the environmental assessment of the supercompactor at the RFETS (DOE, 1990a).

3.3.3.6 Plasma Process

Plasma Processing is significantly different from EMPEIS Cases 6 and 9, incineration and grouting of the ash. However, from the standpoint of potential airborne releases, the two are similar in that both are high temperature processes which would drive off and/or destroy organic hazardous contaminants. The results from EMPEIS Cases 6 and 9 were used as the basis for impacts involving airborne releases. Worker exposure rates would be expected to be similar, and process modeling was performed to account for differences in total operational FTEs.

3.3.3.7 Emplacement Activities

The basis numbers for impact estimates of emplacement activities were taken from the WIPP FSEIS (DOE, 1990b). Industrial accident estimates, which were not available in the FSEIS, were calculated from estimates of FTEs required to perform waste handling, emplacement, and backfill activities and incident rates for salt mine operation from nationwide reported industry experience from 1978 through 1993 (U.S. Department of Labor, 1978-1993). Some types of accidents that contribute heavily to the incident rates for ordinary salt mining would not be involved in WIPP operations. Data on the contribution of types of accidents to the numbers of incidents (D'Appolonia Consulting Engineers, Inc., 1976) were used to refine the estimate of the number of incidents at the WIPP. The following assumptions were made in the analysis of the impacts of accidents involved in waste handling at the WIPP, emplacement, and backfill activities:

- The WIPP operational life is assumed to be 35 years, and emplacement operations will continue over the entire lifetime.

- Waste receipt and emplacement is based on 2 shifts per day, 5 days per week, 20 days per month for the 35 years of operational life of the WIPP.

- Based on industry experience (Hartman, 1992) backfill operations are expected to be performed as a batch operation functioning an average of 4 hours per day, 5 days per week, 20 days per month for the 35 years of operational life.

- Because of the differences between salt mining and WIPP emplacement and backfill activities, the following types of accidents are assumed not to be significant sources of accidental injuries or fatalities: falls of the roof, face, or sides of panels; explosives handling, fires, and explosions.

- Worker risk at the WIPP analyzed in this section does not include mining of panels or associated activities.

- Above-ground support activities not associated with waste handling are not included in this impact analysis.

3.3.3.8 Other Data

The polynomial equations used to estimate FTEs as a function of process throughput were created from manpower curves developed for the EMPEIS facility cost estimates (Feizollahi and Shropshire, 1994).

The estimates for waste process throughput volumes were taken from data developed for Section 3.8.

3.3.3.9 Sources of Uncertainty

Most of the estimates for human health impacts are based on numbers reported in the EMPEIS. These are based on generic designs for hypothetical facilities, not on measured dose or release rates of currently constructed and operating facilities. The use of those results includes uncertainty associated with those estimates, including uncertainties from definition of the physical setting; model applicability and assumptions; fate, transport, and exposure parameters; and toxicity and risk characterization. Other data used in the analysis, such as the waste quantities and FTE estimates, have uncertainties associated with them.

While the modeling process in the EMPEIS was refined as much as possible for individual facilities, the estimates were not intended to indicate absolute risks for any alternative or facility. The intent of the analysis in the EMPEIS and also in this document was to provide estimates of relative risks between alternatives. Because of that, any systematic errors in the modeling would tend to be diminished in the final analysis since the same errors would be applied to each case.

The largest single source of uncertainty in this analysis arises from applying the EMPEIS models to the alternatives. Two extensions have been made, which are potential sources of error. There are no adequate data available to allow the estimation of how much error may be involved in applying results from the analysis of processes selected in the EMPEIS to those selected in this report. Because this report also considers a complete set of configurations for each waste handling process, there are additional uncertainties involved in the extension of EMPEIS alternative data to additional configurations.

Other potential sources of uncertainty are listed below. These, however, are considered of minor consequence compared to those mentioned above. It is unlikely that any of these uncertainties have any measurable impact on the final results but are listed primarily for thoroughness.

- The EMPEIS calculations include adjustments for the isotopic mixtures expected at each facility based on available radionuclide inventories. As wastes from different sites were combined to allow analysis of configurations not analyzed in the EMPEIS, no adjustment was made to account for changes in the resulting radionuclide inventories.

- The EMPEIS analysis addressed how much of the waste from each site was readily retrievable, how much would require potentially difficult retrieval (such as retrieval of buried waste for which container integrity may have been compromised), and how much was newly generated. Each of these sources of waste yields different values for airborne releases and potential worker exposures. Individual site scaling factors were developed using the differences between the waste inventory used in the EMPEIS and the more current inventory figures used by the EACBS in this report. Thus the scaling factors use an inherent assumption that the ratio of retrieved waste to newly generated waste does not change. Actual increases in waste throughput at each facility would result from changes in the quantity of newly generated waste rather than changes in the quantity of retrieved waste.

- Model adjustments were performed for changes in total waste volumes on a site-by-site basis. Although changes in the organic:inorganic:sludge ratios would affect both worker doses and airborne releases, available data were insufficient to allow accounting for those differences.

- The EMPEIS does not assume any storage at the WIPP. All EMPEIS alternatives for TRU waste include storage at the location where the waste is processed. Storage does not increase airborne releases but does increase worker doses from required inspections and maintenance. However, these doses would be expected to be directly proportional to waste volume and relatively unaffected by waste form. In-storage inspection does not benefit from efficiencies of scale. Although different waste forms may be expected to have different dose rates, any increases in dose rates are offset by decreases in the total volume requiring inspection and emplacement. Thus, while the EMPEIS worker doses on which the alternatives are based include doses from long-term waste storage, the effect is applied to all processes and configurations and does not change the relative assessment of those alternatives.

3.3.4 Results of Analysis

Tables 3-11 through 3-28 contain the results of the human health impact analysis for processing and emplacing CH-TRU waste. RH-TRU waste was not evaluated for human health impacts as part of the EACBS. All impacts are expressed as impacts accumulated over a 20-year operating lifetime of the waste processing facilities.

System-wide human health impacts for the baseline and four processing options described in Section 3.3.2 and the three processing configurations are shown in Tables 3-11 through 3-23. Each table displays the impacts as detailed in Table 3-9 for a single processing option and configuration. The injuries and fatalities from industrial accidents are further divided into impacts associated with construction and operations activities. Each table also lists the waste processing facility associated with the most exposed individual impacts reported in the body of the table.

TABLE 3-11

SYSTEM-WIDE HUMAN HEALTH IMPACTS PREPARE AND CERTIFY WASTE TO WIPP ACCEPTANCE CRITERIA AT 10 LOCATIONS BASELINE

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	3.73×10^{-02}			
	Excess Fatalities	1.78×10^{-05}			
	Excess Cancers		5.51×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	1.54×10^{-05}			
	Excess Risk	7.78×10^{-09}			
	Excess Cancers		1.44×10^{-11}		
	Hazard Index			2.27×10^{-09}	
Off-site Population	Dose (Person-rem)	3.89×10^{-01}			
	Excess Fatalities	1.94×10^{-04}			
	Excess Cancers		2.11×10^{-07}		
Most Exposed Off-site Individual	Dose (Rem)	2.14×10^{-05}			
	Excess Risk	1.11×10^{-08}			
	Excess Cancers		5.44×10^{-12}		
	Hazard Index			2.92×10^{-10}	
Workers	Dose (FTE-rem)	$1.94 \times 10^{+03}$			
	Excess Fatalities	7.78×10^{-01}			
	Excess Cancers		1.30×10^{-05}		
	Exposure Index			4.02×10^{-05}	
	Construction Fatalities				9.92×10^{-01}
	Construction Injuries				$8.52 \times 10^{+02}$
	Operations Fatalities				$1.81 \times 10^{+00}$
	Operations Injuries				$7.65 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1 **TABLE 3-12**

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SUPERCOMPACTION OF WASTE AT 10 LOCATIONS
ALTERNATIVE CASES 1 AND 77(a–d)

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.00×10^{-01}			
	Excess Fatalities	2.50×10^{-05}			
	Excess Cancers		9.06×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.34×10^{-05}			
	Excess Risk	1.20×10^{-08}			
	Excess Cancers		2.34×10^{-11}		
	Hazard Index			3.90×10^{-09}	
Off-site Population	Dose (person-rem)	5.31×10^{-01}			
	Excess Fatalities	2.65×10^{-04}			
	Excess Cancers		3.59×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	5.29×10^{-05}			
	Excess Risk	2.61×10^{-08}			
	Excess Cancers		1.82×10^{-11}		
	Hazard Index			8.32×10^{-10}	
Workers	Dose (FTE-rem)	$2.42 \times 10^{+03}$			
	Excess Fatalities	9.54×10^{-01}			
	Excess Cancers		3.03×10^{-05}		
	Exposure Index			4.69×10^{-05}	
	Construction Fatalities				$1.47 \times 10^{+00}$
	Construction Injuries				$1.28 \times 10^{+03}$
	Operations Fatalities				$2.57 \times 10^{+00}$
	Operations Injuries				$1.14 \times 10^{+03}$

The most exposed off-site individual is associated with Los Alamos National Lab

1 **TABLE 3-13**

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SUPERCOMPACTION OF WASTE AT FIVE LOCATIONS
ALTERNATIVE CASES 1 AND 77(a–d)

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.13×10^{-01}			
	Excess Fatalities	2.57×10^{-05}			
	Excess Cancers		9.30×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.41×10^{-05}			
	Excess Risk	1.24×10^{-08}			
	Excess Cancers		2.41×10^{-11}		
	Hazard Index			4.01×10^{-09}	
Off-site Population	Dose (person-rem)	5.45×10^{-01}			
	Excess Fatalities	2.73×10^{-04}			
	Excess Cancers		3.69×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	2.72×10^{-05}			
	Excess Risk	1.34×10^{-08}			
	Excess Cancers		9.33×10^{-12}		
	Hazard Index			4.28×10^{-10}	
Workers	Dose (FTE-rem)	$2.52 \times 10^{+03}$			
	Excess Fatalities	9.92×10^{-01}			
	Excess Cancers		3.15×10^{-05}		
	Exposure Index			4.88×10^{-05}	
	Construction Fatalities				$1.16 \times 10^{+00}$
	Construction Injuries				$1.00 \times 10^{+03}$
	Operations Fatalities				$2.68 \times 10^{+00}$
	Operations Injuries				$1.18 \times 10^{+03}$

The most exposed off-site individual is associated with Los Alamos National Lab

TABLE 3-14

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SUPERCOMPACTION OF WASTE AT ONE LOCATION
ALTERNATIVE CASES 1 AND 77(a–d)

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	7.99×10^{-01}			
	Excess Fatalities	3.99×10^{-05}			
	Excess Cancers		1.45×10^{-07}		
Most Exposed Co-located Individual	Dose (rem)	3.74×10^{-05}			
	Excess Risk	1.92×10^{-08}			
	Excess Cancers		3.74×10^{-11}		
	Hazard Index			6.24×10^{-09}	
Off-site Population	Dose (person-rem)	8.49×10^{-01}			
	Excess Fatalities	4.24×10^{-04}			
	Excess Cancers		5.74×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	3.17×10^{-04}			
	Excess Risk	1.56×10^{-07}			
	Excess Cancers		1.09×10^{-10}		
	Hazard Index			4.98×10^{-09}	
Workers	Dose (FTE-rem)	$2.79 \times 10^{+03}$			
	Excess Fatalities	$1.10 \times 10^{+00}$			
	Excess Cancers		3.49×10^{-05}		
	Exposure Index			5.41×10^{-05}	
	Construction Fatalities				8.18×10^{-01}
	Construction Injuries				$7.11 \times 10^{+02}$
	Operations Fatalities				$2.97 \times 10^{+00}$
	Operations Injuries				$1.31 \times 10^{+03}$

The most exposed off-site individual is associated with WIPP

TABLE 3-15

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND COMPACT WASTE AT 10 LOCATIONS
ALTERNATIVE CASE 6

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	5.00×10^{-01}			
	Excess Fatalities	2.50×10^{-05}			
	Excess Cancers		9.06×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.34×10^{-05}			
	Excess Risk	1.20×10^{-08}			
	Excess Cancers		2.34×10^{-11}		
	Hazard Index			3.90×10^{-09}	
Off-site Population	Dose (person-rem)	5.31×10^{-01}			
	Excess Fatalities	2.65×10^{-04}			
	Excess Cancers		3.59×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	5.29×10^{-05}			
	Excess Risk	2.61×10^{-08}			
	Excess Cancers		1.82×10^{-11}		
	Hazard Index			8.32×10^{-10}	
Workers.	Dose (FTE-rem)	$2.01 \times 10^{+03}$			
	Excess Fatalities	7.91×10^{-01}			
	Excess Cancers		2.51×10^{-05}		
	Exposure Index			3.89×10^{-05}	
	Construction Fatalities				$1.65 \times 10^{+00}$
	Construction Injuries				$1.43 \times 10^{+03}$
	Operations Fatalities				$2.13 \times 10^{+00}$
	Operations Injuries				$9.41 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1 TABLE 3-16

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND COMPACT WASTE AT FIVE LOCATIONS
ALTERNATIVE CASE 6

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	5.13×10^{-01}			
	Excess Fatalities	2.57×10^{-05}			
	Excess Cancers		9.30×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.41×10^{-05}			
	Excess Risk	1.24×10^{-08}			
	Excess Cancers		2.41×10^{-11}		
	Hazard Index			4.01×10^{-09}	
Off-site Population	Dose (person-rem)	5.45×10^{-01}			
	Excess Fatalities	2.73×10^{-04}			
	Excess Cancers		3.69×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	2.72×10^{-05}			
	Excess Risk	1.34×10^{-08}			
	Excess Cancers		9.33×10^{-12}		
	Hazard Index			4.28×10^{-10}	
Workers	Dose (FTE-rem)	$2.06 \times 10^{+03}$			
	Excess Fatalities	8.12×10^{-01}			
	Excess Cancers		2.58×10^{-05}		
	Exposure Index			4.00×10^{-05}	
	Construction Fatalities				$1.26 \times 10^{+00}$
	Construction Injuries				$1.09 \times 10^{+03}$
	Operations Fatalities				$2.19 \times 10^{+00}$
	Operations Injuries				$9.67 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1 **TABLE 3-17**

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND COMPACT WASTE AT ONE LOCATION
ALTERNATIVE CASE 6

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	7.99×10^{-01}			
	Excess Fatalities	3.99×10^{-05}			
	Excess Cancers		1.45×10^{-07}		
Most Exposed Co-located Individual	Dose (rem)	3.74×10^{-05}			
	Excess Risk	1.92×10^{-08}			
	Excess Cancers		3.74×10^{-11}		
	Hazard Index			6.24×10^{-09}	
Off-site Population	Dose (person-rem)	8.49×10^{-01}			
	Excess Fatalities	4.24×10^{-04}			
	Excess Cancers		5.74×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	9.29×10^{-05}			
	Excess Risk	4.58×10^{-08}			
	Excess Cancers		3.18×10^{-11}		
	Hazard Index			1.46×10^{-09}	
Workers	Dose (FTE-rem)	$3.04 \times 10^{+03}$			
	Excess Fatalities	$1.20 \times 10^{+00}$			
	Excess Cancers		3.80×10^{-05}		
	Exposure Index			5.90×10^{-05}	
	Construction Fatalities				8.44×10^{-01}
	Construction Injuries				$7.35 \times 10^{+02}$
	Operations Fatalities				$3.23 \times 10^{+00}$
	Operations Injuries				$1.43 \times 10^{+03}$

The most exposed off-site individual is associated with WIPP

1 **TABLE 3-18**

SYSTEM-WIDE HUMAN HEALTH IMPACTS
PLASMA PROCESSING OF WASTE AT 10 LOCATIONS
ALTERNATIVE CASE 10

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	$9.61 \times 10^{+02}$			
	Excess Fatalities	4.73×10^{-01}			
	Excess Cancers		7.80×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	6.82×10^{-01}			
	Excess Risk	3.34×10^{-04}			
	Excess Cancers		2.09×10^{-11}		
	Hazard Index			1.81×10^{-07}	
Off-site Population	Dose (person-rem)	$9.33 \times 10^{+03}$			
	Excess Fatalities	$4.60 \times 10^{+00}$			
	Excess Cancers		3.06×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	4.92×10^{-01}			
	Excess Risk	2.54×10^{-04}			
	Excess Cancers		1.82×10^{-11}		
	Hazard Index			4.17×10^{-08}	
Workers	Dose (FTE-rem)	$2.88 \times 10^{+03}$			
	Excess Fatalities	$1.17 \times 10^{+00}$			
	Excess Cancers		4.81×10^{-05}		
	Exposure Index			1.65×10^{-03}	
	Construction Fatalities				$4.73 \times 10^{+00}$
	Construction Injuries				$3.94 \times 10^{+03}$
	Operations Fatalities				$5.00 \times 10^{+00}$
	Operations Injuries				$2.12 \times 10^{+03}$

The most exposed off-site individual is associated with Los Alamos National Lab

TABLE 3-19

SYSTEM-WIDE HUMAN HEALTH IMPACTS
PLASMA PROCESSING OF WASTE AT FIVE LOCATIONS
ALTERNATIVE CASE 10

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	$1.00 \times 10^{+03}$			
	Excess Fatalities	4.93×10^{-01}			
	Excess Cancers		8.13×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	7.11×10^{-01}			
	Excess Risk	3.48×10^{-04}			
	Excess Cancers		2.18×10^{-11}		
	Hazard Index			1.89×10^{-07}	
Off-site Population	Dose (person-rem)	$9.72 \times 10^{+03}$			
	Excess Fatalities	$4.79 \times 10^{+00}$			
	Excess Cancers		3.19×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	2.53×10^{-01}			
	Excess Risk	1.30×10^{-04}			
	Excess Cancers		9.34×10^{-12}		
	Hazard Index			2.14×10^{-08}	
Workers	Dose (FTE-rem)	$2.24 \times 10^{+03}$			
	Excess Fatalities	9.10×10^{-01}			
	Excess Cancers		3.73×10^{-05}		
	Exposure Index			1.28×10^{-03}	
	Construction Fatalities				$3.31 \times 10^{+00}$
	Construction Injuries				$2.75 \times 10^{+03}$
	Operations Fatalities				$3.88 \times 10^{+00}$
	Operations Injuries				$1.64 \times 10^{+03}$

The most exposed off-site individual is associated with Los Alamos National Lab

1 **TABLE 3-20**

SYSTEM-WIDE HUMAN HEALTH IMPACTS
PLASMA PROCESSING OF WASTE AT ONE LOCATION
ALTERNATIVE CASE 10

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	$1.46 \times 10^{+02}$			
	Excess Fatalities	7.37×10^{-02}			
	Excess Cancers		9.73×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	5.60×10^{-01}			
	Excess Risk	2.80×10^{-04}			
	Excess Cancers		2.21×10^{-11}		
	Hazard Index			6.78×10^{-07}	
Off-site Population	Dose (person-rem)	$1.77 \times 10^{+03}$			
	Excess Fatalities	8.99×10^{-01}			
	Excess Cancers		3.39×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	4.72×10^{-01}			
	Excess Risk	2.36×10^{-04}			
	Excess Cancers		7.07×10^{-12}		
	Hazard Index			1.12×10^{-07}	
Workers	Dose (FTE-rem)	$3.34 \times 10^{+03}$			
	Excess Fatalities	$1.34 \times 10^{+00}$			
	Excess Cancers		1.69×10^{-04}		
	Exposure Index			2.16×10^{-03}	
	Construction Fatalities				$1.75 \times 10^{+00}$
	Construction Injuries				$1.61 \times 10^{+03}$
	Operations Fatalities				$3.54 \times 10^{+00}$
	Operations Injuries				$1.55 \times 10^{+03}$

The most exposed off-site individual is associated with WIPP

TABLE 3-21

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND ADD CLAY TO WASTE AT 10 LOCATIONS
ALTERNATIVE CASES 94(a–f)

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.00×10^{-01}			
	Excess Fatalities	2.50×10^{-05}			
	Excess Cancers		9.06×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.34×10^{-05}			
	Excess Risk	1.20×10^{-08}			
	Excess Cancers		2.34×10^{-11}		
	Hazard Index			3.90×10^{-09}	
Off-site Population	Dose (person-rem)	5.31×10^{-01}			
	Excess Fatalities	2.65×10^{-04}			
	Excess Cancers		3.59×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	5.29×10^{-05}			
	Excess Risk	2.61×10^{-08}			
	Excess Cancers		1.82×10^{-11}		
	Hazard Index			8.32×10^{-10}	
Workers	Dose (FTE-rem)	$2.01 \times 10^{+03}$			
	Excess Fatalities	7.91×10^{-01}			
	Excess Cancers		2.51×10^{-05}		
	Exposure Index			3.89×10^{-05}	
	Construction Fatalities				$1.65 \times 10^{+00}$
	Construction Injuries				$1.43 \times 10^{+03}$
	Operations Fatalities				$2.13 \times 10^{+00}$
	Operations Injuries				$9.41 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1 TABLE 3-22

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND ADD CLAY TO WASTE AT FIVE LOCATIONS
ALTERNATIVE CASES 94(a–f)

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	5.13×10^{-01}			
	Excess Fatalities	2.57×10^{-05}			
	Excess Cancers		9.30×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.41×10^{-05}			
	Excess Risk	1.24×10^{-08}			
	Excess Cancers		2.41×10^{-11}		
	Hazard Index			4.01×10^{-09}	
Off-site Population	Dose (person-rem)	5.45×10^{-01}			
	Excess Fatalities	2.73×10^{-04}			
	Excess Cancers		3.69×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	2.72×10^{-05}			
	Excess Risk	1.34×10^{-08}			
	Excess Cancers		9.33×10^{-12}		
	Hazard Index			4.28×10^{-10}	
Workers	Dose (FTE-rem)	$2.06 \times 10^{+03}$			
	Excess Fatalities	8.12×10^{-01}			
	Excess Cancers		2.58×10^{-05}		
	Exposure Index			4.00×10^{-05}	
	Construction Fatalities				$1.26 \times 10^{+00}$
	Construction Injuries				$1.09 \times 10^{+03}$
	Operations Fatalities				$2.19 \times 10^{+00}$
	Operations Injuries				$9.67 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1 **TABLE 3-23**

SYSTEM-WIDE HUMAN HEALTH IMPACTS SHRED AND ADD CLAY TO WASTE AT ONE LOCATION ALTERNATIVE CASES 94(a–f)

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	7.99×10^{-01}			
	Excess Fatalities	3.99×10^{-05}			
	Excess Cancers		1.45×10^{-07}		
Most Exposed Co-located Individual	Dose (rem)	3.74×10^{-05}			
	Excess Risk	1.92×10^{-08}			
	Excess Cancers		3.74×10^{-11}		
	Hazard Index			6.24×10^{-09}	
Off-site Population	Dose (person-rem)	8.49×10^{-01}			
	Excess Fatalities	4.24×10^{-04}			
	Excess Cancers		5.74×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	9.29×10^{-05}			
	Excess Risk	4.58×10^{-08}			
	Excess Cancers		3.18×10^{-11}		
	Hazard Index			1.46×10^{-09}	
Workers	Dose (FTE-rem)	$3.04 \times 10^{+03}$			
	Excess Fatalities	$1.20 \times 10^{+00}$			
	Excess Cancers		3.80×10^{-05}		
	Exposure Index			5.90×10^{-05}	
	Construction Fatalities				8.44×10^{-01}
	Construction Injuries				$7.35 \times 10^{+02}$
	Operations Fatalities				$3.23 \times 10^{+00}$
	Operations Injuries				$1.43 \times 10^{+03}$

The most exposed off-site individual is associated with WIPP

TABLE 3-24

SUMMARY OF ENGINEERED ALTERNATIVES HUMAN HEALTH IMPACTS CONTACT-HANDLED TRU WASTE RISKS TO TOTAL POPULATIONS BY WASTE TREATMENT AND CONFIGURATION

EA Number	Treatment Process	Configuration	Off-site Population CF[1]	Off-site Population CI[2]	Co-located Workers CF	Co-located Workers CI	Workers CF	Workers CI	C&OF[3]
0	Baseline	Ten sites	1.94×10^{-04}	5.51×10^{-08}	1.78×10^{-05}	1.44×10^{-11}	7.78×10^{-01}	1.30×10^{-05}	2.81
1	Supercompaction	Ten sites	2.65×10^{-04}	3.59×10^{-07}	2.50×10^{-05}	9.06×10^{-08}	9.54×10^{-01}	3.03×10^{-05}	4.05
1	Supercompaction	Five sites	2.73×10^{-04}	3.69×10^{-07}	2.57×10^{-05}	9.30×10^{-08}	9.92×10^{-01}	3.15×10^{-05}	3.83
1	Supercompaction	One site	4.24×10^{-04}	5.74×10^{-07}	3.99×10^{-05}	1.45×10^{-07}	$1.10 \times 10^{+00}$	3.49×10^{-05}	3.79
6	Shred and Compact	Ten sites	2.65×10^{-04}	3.59×10^{-07}	2.50×10^{-05}	9.06×10^{-08}	7.91×10^{-01}	2.51×10^{-05}	3.78
6	Shred and Compact	Five sites	2.73×10^{-04}	3.69×10^{-07}	2.57×10^{-05}	9.30×10^{-08}	8.12×10^{-01}	2.58×10^{-05}	3.45
6	Shred and Compact	One site	4.24×10^{-04}	5.74×10^{-07}	3.99×10^{-05}	1.45×10^{-07}	$1.20 \times 10^{+00}$	3.80×10^{-05}	4.08
10	Plasma Processing	Ten sites	$4.60 \times 10^{+00}$	3.06×10^{-07}	4.73×10^{-01}	7.80×10^{-08}	$1.17 \times 10^{+00}$	4.81×10^{-05}	9.73
10	Plasma Processing	Five sites	$4.79 \times 10^{+00}$	3.19×10^{-07}	4.93×10^{-01}	8.13×10^{-08}	9.10×10^{-01}	3.73×10^{-05}	7.18
10	Plasma Processing	One site	8.99×10^{-01}	3.39×10^{-07}	7.37×10^{-02}	9.73×10^{-08}	$1.34 \times 10^{+00}$	1.69×10^{-04}	5.29
94	Shred and Add Clay	Ten sites	2.65×10^{-04}	3.59×10^{-07}	2.50×10^{-05}	9.06×10^{-08}	7.91×10^{-01}	2.51×10^{-05}	3.78
94	Shred and Add Clay	Five sites	2.73×10^{-04}	3.69×10^{-07}	2.57×10^{-05}	9.30×10^{-08}	8.12×10^{-01}	2.58×10^{-05}	3.45
94	Shred and Add Clay	One site	4.24×10^{-04}	5.74×10^{-07}	3.99×10^{-05}	1.45×10^{-07}	$1.20 \times 10^{+00}$	3.80×10^{-05}	4.08

[1]CF—cancer fatality.
[2]CI—cancer incidence.
[3]C&OF—fatalities from physical hazards during construction and operating activities.

TABLE 3-25

SUMMARY OF ENGINEERED ALTERNATIVES HUMAN HEALTH IMPACTS CONTACT-HANDLED TRU WASTE RISKS TO OFF-SITE AND CO-LOCATED WORKERS BY WASTE TREATMENT AND CONFIGURATION

EA Number	Treatment Process	Configuration	Most Exposed Off-site Individual			Most Exposed Co-located Worker			Associated Site
			CF[2]	CI[2]	HI[3]	CF	CI	HI	
0	Baseline	Ten sites	1.11×10^{-08}	5.44×10^{-12}	2.92×10^{-10}	7.78×10^{-09}	1.44×10^{-11}	2.27×10^{-09}	Los Alamos National Lab
1	Supercompaction	Ten sites	2.61×10^{-08}	1.82×10^{-11}	8.32×10^{-10}	1.20×10^{-08}	2.34×10^{-11}	3.90×10^{-09}	Los Alamos National Lab
1	Supercompaction	Five sites	1.34×10^{-08}	9.33×10^{-12}	4.28×10^{-10}	1.24×10^{-08}	2.41×10^{-11}	4.01×10^{-09}	Los Alamos National Lab
1	Supercompaction	One site	1.56×10^{-07}	1.09×10^{-10}	4.98×10^{-09}	3.99×10^{-05}	3.74×10^{-11}	6.24×10^{-09}	WIPP
6	Shred and Compact	Ten sites	2.61×10^{-08}	1.82×10^{-11}	8.32×10^{-10}	1.20×10^{-08}	2.34×10^{-11}	3.90×10^{-09}	Los Alamos National Lab
6	Shred and Compact	Five sites	1.34×10^{-08}	9.33×10^{-12}	4.28×10^{-10}	1.24×10^{-08}	2.41×10^{-11}	4.01×10^{-09}	Los Alamos National Lab
6	Shred and Compact	One site	4.58×10^{-08}	3.18×10^{-11}	1.46×10^{-09}	1.92×10^{-08}	3.74×10^{-11}	6.24×10^{-09}	WIPP
10	Plasma Processing	Ten sites	2.54×10^{-04}	1.82×10^{-11}	4.17×10^{-08}	3.34×10^{-04}	2.09×10^{-11}	1.81×10^{-07}	Los Alamos National Lab
10	Plasma Processing	Five sites	1.30×10^{-04}	9.34×10^{-12}	2.14×10^{-08}	3.48×10^{-04}	2.18×10^{-11}	1.89×10^{-07}	Los Alamos National Lab
10	Plasma Processing	One site	2.36×10^{-04}	7.07×10^{-12}	1.12×10^{-07}	2.80×10^{-04}	2.21×10^{-11}	6.78×10^{-07}	WIPP
94	Shred and Add Clay	Ten sites	2.61×10^{-08}	1.82×10^{-11}	8.32×10^{-10}	1.20×10^{-08}	2.34×10^{-11}	3.90×10^{-09}	Los Alamos National Lab
94	Shred and Add Clay	Five sites	1.34×10^{-08}	9.33×10^{-12}	4.28×10^{-10}	1.24×10^{-08}	2.41×10^{-11}	4.01×10^{-09}	Los Alamos National Lab
94	Shred and Add Clay	One site	4.58×10^{-08}	3.18×10^{-11}	1.46×10^{-09}	1.92×10^{-08}	3.74×10^{-11}	6.24×10^{-09}	WIPP

[1]CF—cancer fatality.
[2]CI—cancer incidence.
[3]HI—hazard index.

1 **TABLE 3-26**

SUMMARY OF HUMAN HEALTH IMPACTS ASSOCIATED WITH CH-TRU WASTE EMPLACEMENT AT THE WIPP RADIATION IMPACTS

EA Number	Case Description	Workers		Most Exposed Off-site		Collective Off-site	
		Doses (FTE-rem)	Excess Fatalities	Doses (rem)	Excess Risk	Doses (person-rem)	Excess Fatalities
0	Baseline	322.85	0.13	6.65×10^{-05}	3.32×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
1	Supercompaction	322.85	0.13	6.65×10^{-05}	3.32×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
6	Shred and Compact	322.85	0.13	3.73×10^{-05}	1.87×10^{-08}	1.75×10^{-02}	8.75×10^{-06}
10	Plasma Processing	322.85	0.13	5.57×10^{-05}	2.79×10^{-08}	6.00×10^{-03}	3.00×10^{-06}
33	Sand plus Clay Backfill	345.27	0.14	1.91×10^{-05}	9.54×10^{-09}	2.09×10^{-02}	1.04×10^{-05}
35a	Salt Aggregate Grout Backfill	357.23	0.14	6.65×10^{-05}	3.32×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
35b	Cementitious Grout Backfill	357.23	0.14	6.65×10^{-05}	3.32×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
111	Clay Based Backfill	342.28	0.14	6.65×10^{-05}	3.32×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
77a	Supercompact with Salt Aggregate Grout	342.07	0.14	6.65×10^{-05}	3.32×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
77b	Supercompact with Clay Based Backfill	340.15	0.14	3.73×10^{-05}	1.87×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
77c	Supercompact with Sand and Clay Backfill	343.99	0.14	3.73×10^{-05}	1.87×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
77d	Supercompact with Cao Backfill	338.23	0.14	3.73×10^{-05}	1.87×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
83	Cao Backfill	339.29	0.14	3.73×10^{-05}	1.87×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
94a	Shred and Add Clay to Waste	322.85	0.13	6.65×10^{-05}	3.32×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94b	Shred and Add Clay, Clay/sand Backfill	346.77	0.14	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94c	Shred and Add Clay, Cementitious Grout	366.20	0.15	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94d	Shred and Add Clay, Salt Aggregate Grout	343.78	0.14	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94e	Shred and Add Clay to Waste, Clay Backfill	342.28	0.14	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94f	Shred and Add Clay to Waste Cao Backfill	339.29	0.14	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}

TABLE 3-27

SUMMARY OF HUMAN HEALTH IMPACTS ASSOCIATED WITH CH-TRU WASTE EMPLACEMENT AT THE WIPP HAZARDOUS AND TOXIC CHEMICAL IMPACTS

EA Number	Case Description	Carcinogenic Chemicals (Excess Cancers)			Toxic Chemicals (Hazard Index)		
		Workers	Most Exposed Co-located	Most Exposed Off-site	Workers	Most Exposed Co-located	Most Exposed Off-site
0	Baseline	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
1	Supercompaction	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
6	Shred and Compact	1.03×10^{-05}	2.55×10^{-10}	2.15×10^{-10}	1.43×10^{-03}	3.58×10^{-08}	6.61×10^{-09}
10	Plasma Processing	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$
33	Sand plus Clay Backfill	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
35a	Salt Aggregate Grout	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
35b	Cementitious Grout	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
111	Clay Based Backfill	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
77a	Supercompact with	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
77b	Supercompact with	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
77c	Supercompact with	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
77d	Supercompact with	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
83	Cao Backfill	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
94a	Shred and Add Clay to	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94b	Shred and Add Clay,	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94c	Shred and Add Clay,	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94d	Shred and Add Clay,	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94e	Shred and Add Clay to	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94f	Shred and Add Clay to	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}

1 **TABLE 3-28**

SUMMARY OF HUMAN HEALTH IMPACTS ASSOCIATED CH-TRU WASTE EMPLACEMENT AT THE WIPP WORKER INDUSTRIAL ACCIDENTS

EA Number	Case Description	Injuries	Fatalities
0	Baseline	53.63	0.16
1	Supercompaction	44.05	0.13
6	Shred and Compact	44.05	0.13
10	Plasma Processing	33.20	0.10
33	Sand plus Clay Backfill	64.50	0.29
35a	Salt Aggregate Grout Backfill	70.81	0.30
35b	Cementitious Grout Backfill	70.81	0.30
111	Clay Based Backfill	62.53	0.18
77a	Supercompact with Salt Aggregate Grout	55.53	0.15
77b	Supercompact with Clay Based Backfill	49.80	0.15
77c	Supercompact with Sand and Clay Backfill	51.77	0.15
77d	Supercompact with Cao Backfill	51.06	0.25
83	CaO Backfill	66.45	0.28
94a	Shred and Add Clay to Waste	53.63	0.16
94b	Shred and Add Clay to Waste Clay and Sand Backfill	67.04	0.39
94c	Shred and Add Clay to Waste Cementitious Grout Backfill	69.14	0.21
94d	Shred and Add Clay to Waste Salt Aggregate Grout Backfill	69.56	0.49
94e	Shred and Add Clay to Waste Clay Based Backfill	61.83	0.18
94f	Shred and Add Clay to Waste Cao Backfill	63.25	0.28

Table 3-24 shows a summary of the system-wide cumulative impacts on workers, co-located workers, and the off-site population for all combinations of waste processes and configurations. The impacts included in this table are the excess cancer fatalities from radiation exposure, excess cancer incidence from hazardous chemical exposure, and worker fatalities from industrial accidents. Table 3-25 contains similar data for the most exposed off-site individual and most exposed co-located worker. The impacts of industrial accidents from handling CH-TRU waste are not applicable to co-located workers and off-site individuals and are not included on Table 3-25. The table does add the Hazard Index for the most exposed individuals as well as the facility at which the highest individual impact was determined.

Tables 3-26 through 3-28 show summaries of the impacts on workers, co-located workers, and the off-site population from emplacement activities at the WIPP. Each combination of waste processing and emplacement backfill are represented because the waste processes generate different waste forms and quantities for equivalent inputs. Differing backfill options affect the amount of time and effort required to complete the emplacement of the waste. Table 3-26 shows the impacts, in terms of both dose and excess fatalities, from collective doses to workers and the off-site population and the total dose to the most exposed off-site individual. Table 3-27 shows the impacts of both carcinogenic and toxic chemicals on workers, the most exposed co-located worker, and the most exposed off-site individual. Table 3-28 shows the injuries and fatal accidents at the WIPP estimated to involve workers over the period analyzed for waste emplacement at the WIPP.

As discussed in Section 3.3.3.9, there are a number of sources of uncertainty, but the largest single source of uncertainty arises from applying EMPEIS models to the alternatives. The equivalence of the scenarios in the EMPEIS and the alternatives vary from very close, such as using the shred and grout from the EMPEIS to simulate shred and add clay in the alternatives, to much more tenuous, such as simulating the plasma processing in the alternatives by the EMPEIS incinerate-and-grout process. The information available is insufficient to allow a numerical estimate of how much uncertainty is introduced by these assumptions, but it is expected that nonsystemic uncertainties should not exceed plus or minus 100 percent of the risk estimates.

The conclusions in the following bullet list may be inferred from the data in Tables 3-11 through 3-28.

- The differences in cancer incidence for workers, co-located workers, and off-site populations are within a factor of two for all processes and configurations. The cancer incidence for the alternatives are the same as for the baseline for workers but four orders of magnitude higher than the baseline for co-located workers and about one order of magnitude for off-site populations. This probably results from adequate control of worker exposure to volatile chemicals in the waste by ventilation controls during waste processing, but vent releases increase with any processing. The baseline does not require opening the waste drums, but all the analyzed waste processes do require some opening of the waste, thus releasing volatile chemicals to be exhausted from the facility vents.

- Cancer fatalities for workers are also within a factor of two for all processes and configurations and for the baseline. The same is true for co-located workers and off-site populations except that cancer fatalities are about four orders of magnitude higher for plasma processing than for the baseline or any other process.

- Cancer fatalities show a general increase with increased consolidation, although differences are less than a factor of two. Only plasma processing does not follow the trend, with centralized impacts showing a slight decrease for off-site populations and co-located workers but an increase for workers.

- Physical hazards show very little difference between process or configurations, including the baseline, except for plasma processing where distributed and regional processing show an increase of two to three times other processes and configurations.

- Somewhat greater differences between configurations might have been expected than were observed for those impacts most affected by the change in FTEs (cancer fatalities and physical hazard fatalities). However, the improvements expected to be provided by the efficiencies of scale are offset by the double handling required to prepare waste at nonprocessing facilities followed by additional handling to receive that waste at the processing site.

- For individuals, risk values of less than 10^{-6} for cancer fatalities or incidence or hazard index values less than one are not considered significant. With the exception of cancer fatalities for plasma processing, none of the impacts to most exposed individuals are considered significant. The variations between processes and configurations do not show variations greater than a factor of two to five except for plasma processing which shows the same four orders of magnitude increase observed in cancer fatalities in groups. Even for cancer fatalities for plasma processing, the annualized risks are between 7×10^{-6} and 2×10^{-5}, just slightly greater than the level of insignificance.

- Impacts for emplacement of the waste at WIPP show only about a factor of two or three between the various alternatives for either radiation or chemical hazard exposure. Plasma processing shows a decrease of approximately five for off-site population risks from radiation, primarily because most of the radioactive material is retained in the waste form. No risks are shown for chemical impacts of emplacement of plasma-processed waste because all the volatile chemicals have either been removed from the waste during processing or are tightly bound within the waste form.

- Fatalities from physical accidents are no more than 1 for the 35-year operational period for any of the alternatives. Both injuries and fatalities for each alternative are within 25 percent of the baseline.

3.4 WASTE REMOVAL IMPACT

3.4.1 Definition of Factor 4

Waste removal is defined as the activity involving recovery of the waste after repository closure. In assessing the waste removal activities, the waste inventory and physical properties for each engineered alternative determine the underground panel geometry that would in turn determine the time required for underground removal. Underground removal considers the compressive strength and density of the waste form as well as the consolidation of the backfill expected to occur after a specified period of time. The occupational hazards for industrial accidents include the conventional hazards due to underground mining accidents, hazardous waste exposure, and radioactive waste exposure.

After waste emplacement, the surrounding salt will be subject to creep with encroachment of the waste occurring after a period of 10 to 20 years. As encroachment occurs, the waste and backfill (if present) consolidate with a reduction of void space. This reduction affects the physical characteristics of the waste with time. The degree of difficulty in removing waste depends on the degree of consolidation at the time of removal, and the physical properties that in turn affect underground waste removal operations. The room geometry and repository layout also affect underground waste removal operations. The evaluation of this factor considers these waste and backfill (if present) properties for the baseline and each alternative at some future point in time when waste removal would be accomplished. This factor determines the impact on the ability to remove waste. No provisions are made with any of the EAs that specifically facilitate removal. Such provisions are not required by the disposal standard.

3.4.2 Methodology Used to Evaluate the Mine Waste Removal Factor (Factor 4)

The main objective of mine waste removal evaluation is to assess the degree of difficulty in extracting waste and backfill and how each of the alternatives influences the associated risk and detriments for each alternative. The factor components include (1) the waste volume and repository layout for each alternative that would determine the number of panels for waste disposal; and (2) the unconfined compressive strength of the waste/backfill that affect the mining advance rate. If a waste form/backfill were selected that would have desirable characteristics for long term isolation (such as a high compressive strength that reduces the release of drill cuttings), it might be undesirable from the mine waste removal in that there would be increased hazards regarding removal.

The baseline for waste removal is evaluated by defining the physical layout for underground waste removal activities. The analysis of industrial hazards suggests that the number of accidents is related to the time required for underground waste removal, and that in turn relates to the underground continuous mining time. Each of the alternatives can be ranked with regard to waste removal subjecting workers to risk. For waste forms exhibiting higher compressive strength (grouted waste, etc.), more time is required for mining and removal with the occurrence of a larger number of nonradiological and radiological accidents and doses.

The unconfined compressive strengths of various waste forms are evaluated using the relationships of compressive strength to porosity. For crushed salt backfill, cementitious materials, and earthen materials, test data were compiled and relationships developed as illustrated in Figure 3-7 (Nelson et al., 1981; Mindess and Young, 1981; U.S. Bureau of

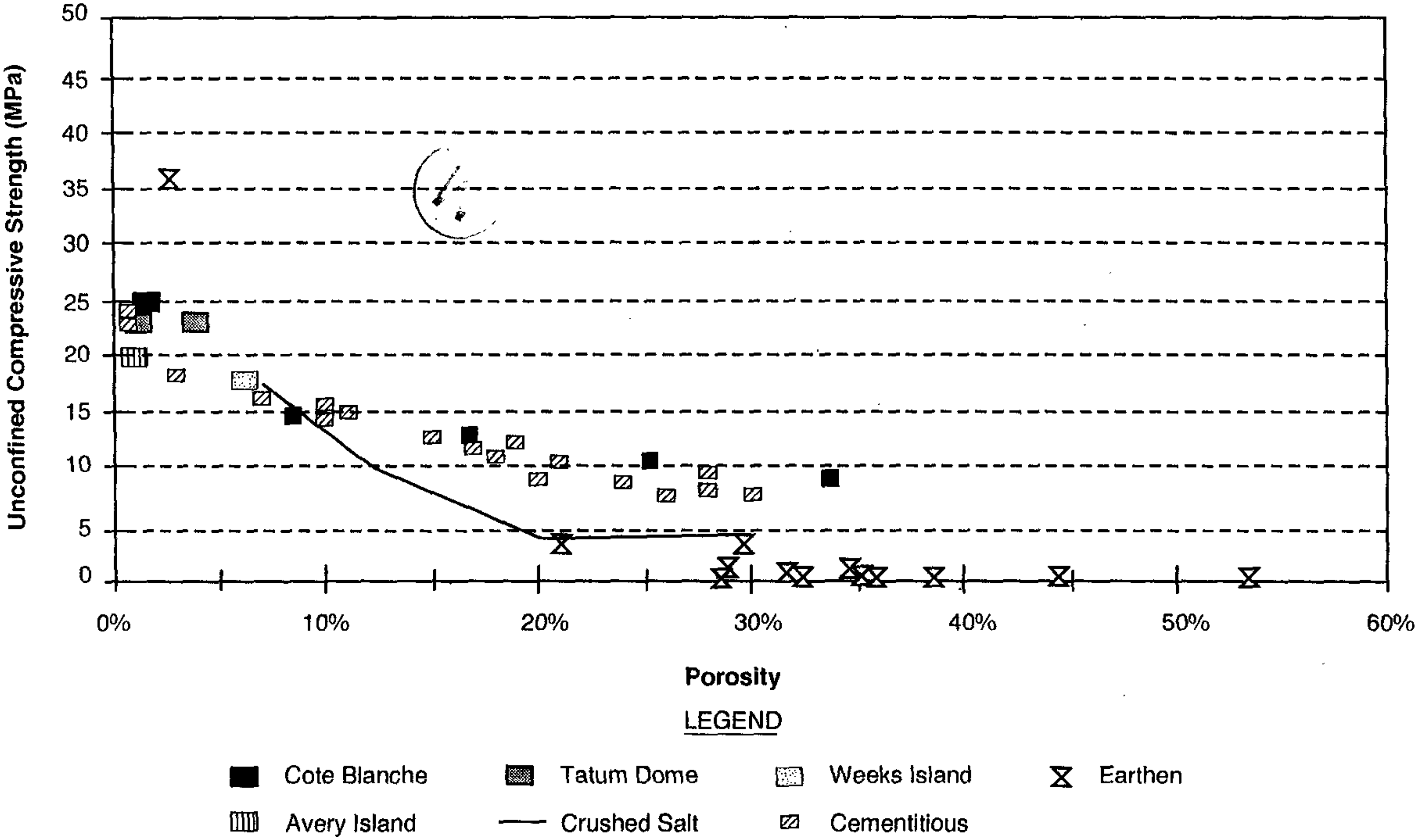


Figure 3-7
Relationship of Unrestricted Compressive Strength to Porosity

Reclamation, 1974; and Winterkorn and Fang, 1977). The test data from these sources show that cementitious materials exhibit a range of low to high porosities with higher compressive strengths, earthen materials (clay, sand) exhibit higher porosities with lower compressive strengths, and that crushed salt exhibits compressive strengths intermediate to these materials. The inorganic or metallic waste would exhibit a much higher compressive strength; yet the effective porosity would be much higher. As discussed subsequently, the mining advance rate was selected to be about one-half of the rate for other waste forms and backfill.

After approximately 100 years, the waste and backfill (if present) would consolidate to a value near lithostatic stress. As stresses buildup on the waste form and backfill, the secondary creep rate would reduce. If waste removal is assumed to occur when the waste compressive stress has reached 90 percent of lithostatic stress (14 MPa), the porosity can be determined for the various materials. The porosity of the various materials at this stress level is presented in Table 3-29. Note that the same relationships for porosity with stress level as used for Factor 1 were considered here. From the unconfined compressive strength vs. porosity relationship presented in Figure 3-7, the approximate compressive strengths can be determined, and then averaged on the basis of volume for each of the materials.

The mining advance rate as a function of compressive strength is determined by relating the specific energy to compressive strength from laboratory disc cutting studies for rocks of various compressive strengths from 50 to 350 MPa (Temporal et al., 1983), and then relating the specific energy to excavation rate (McFeat-Smith and Powell, 1979). In laboratory disc cutting studies, the specific energy in cutting is determined, and then correlated to compressive strength as presented in Figure 3-8. The laboratory procedure was to make a series of cuts on a rock surface to simulate an excavated face, make cuts with the disc cutter on the simulated rock surface while recording the tool force, and length of cut, measure the cut volume, and then determine the specific energy as the tool force times the length of cut divided by the excavation volume. The relationship in Figure 3-8 can then be related to other combined laboratory and field studies where specific energy is determined, and then related to field cutting rates for a typical medium weight roadheader as shown in Figure 3-9. Although other operational parameters such as depth of cut, cutting geometry, line spacing and the degree of wear of the cutting tool, the use of a standard cutting test ensures that variation in specific energy can be directly attributed to the cutting characteristics tested. If consideration is given to a 13 ft by 33 ft (3.96 by 10.06 m) or a 6 ft by 33 ft (1.83 by 10.06 m) room size, the mining advance rate as a function of unconfined compressive strength can be determined as shown in Figure 3-10.

For metallic waste, steel exhibits a high average compressive strength of approximately 30,000 psi (206 MPa).

From the above discussion, the mining advance rate would be smaller than normal mining advance rates. From Temporal, et al., 1983, the specific energy is about 30 MJ/m^3. From McFeat-Smith and Powell, 1979, the mining rate is about 177 ft^3 (5 m^3) per hour. This results in a mining advance rate of 3.3 ft (1 m) per shift, which is about one-half the mining advance rate for other materials.

TABLE 3-29
SUMMARY OF POROSITIES AND COMPRESSIVE STRENGTHS

		Porosity at Lithostatic Pressure				Unconfined Compressive Strength					Average Waste/ Backfill Composite (MPa)
Identifier	Alternative	Sludges[1]	Solid Organic	Solid Inorganic Metals	Backfill	Sludges (MPa)	Solid Organic (MPa)	Solid Inorganic (MPa)	Backfill (MPa)	Host Salt (MPa)	
0	Baseline	12.21%	15.42%	41.72%	—	16	7	75	—	25	25.2
1	Compact Waste	12.21%	15.42%	41.72%	—	16	9	75	—	25	24.5
6	Shred and Compact	12.21%	13.15%	39.16%	—	16	9	75	—	25	25.1
10	Plasma Processing of All Waste	12.21%	12.21%	12.21%	—	16	16	16	—	25	24.1
33	Sand Plus Clay Backfill	12.21%	15.42%	41.72%	33.60%	16	7	75	3	25	15.2
35.a	Salt Aggregate Grout Backfill	12.21%	15.42%	41.72%	31.30%	16	7	75	16	25	21.1
35.b	Cementitious Grout Backfill	12.21%	15.42%	41.72%	31.30%	16	7	75	16	25	21.1
77.a	Supercompact organics and inorganics, salt-aggregate grout backfill, monolayer of 2,000 drums, in 6X33X300	12.21%	24.00%	39.16%	31.30%	16	9	75	16	25	19.4
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums, in 6X33X300	12.21%	13.15%	39.16%	40.50%	16	9	75	3	25	12.2
77.c	Supercompact organics and inorganics, sand plus clay based backfill, monolayer of 2,000 drums, in 6X33X300	12.21%	13.15%	39.16%	33.60%	16	9	75	3	25	12.2
77.d	Supercompact organics and inorganics, CaO based backfill, monolayer of 2,000 drums, in 6X33X300	12.21%	13.15%	39.16%	10.10%	16	9	75	14	25	18.3
83	Salt Backfill with CaO	12.21%	15.42%	41.72%	10.10%	16	7	75	14	25	20.2

TABLE 3-29 (Continued)
SUMMARY OF POROSITIES AND COMPRESSIVE STRENGTHS

Identifier	Alternative	Porosity at Lithostatic Pressure				Unconfined Compressive Strength					Average Composite Waste/ Backfill (MPa)
		Sludges[1]	Solid Organic	Solid Inorganic Metals	Backfill	Sludges (MPa)	Solid Organic (MPa)	Solid Inorganic (MPa)	Backfill (MPa)	Host Salt (MPa)	
94.a	SPM IT-4 Enhanced cement sludges, shred and add clay organics and inorganics, no backfill	20.0%	24.00%	41.30%	—	16	7	75	0	25	24.7
94.b	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, sand plus clay backfill.	20.0%	24.00%	41.30%	33.60%	16	7	75	3	25	14.7
94.c	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, cementitious grout backfill.	20.0%	24.00%	41.30%	31.30%	16	7	75	16	25	20.6
94.d	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.	20.0%	24.00%	41.30%	31.30%	16	7	75	16	25	20.6
94.e	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, clay backfill.	20.0%	24.00%	41.30%	40.50%	16	7	75	3	25	14.7
94.f	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, CaO backfill.	20.0%	24.00%	41.30%	10.10%	16	7	75	14	25	19.7
111	Clay Based Backfill	12.21%	15.42%	41.72%	40.50%	16	7	75	3	25	15.2

[1]Porosity for enhanced cementation is estimated at 20% at 2000 psi stress. The enhanced cemented sludge is assumed to have a compressive strength of greater than 2000 psi. The 20% pore space is assumed to be from entrained air during mixing and does not change with increased pressure up to 2000 psi.

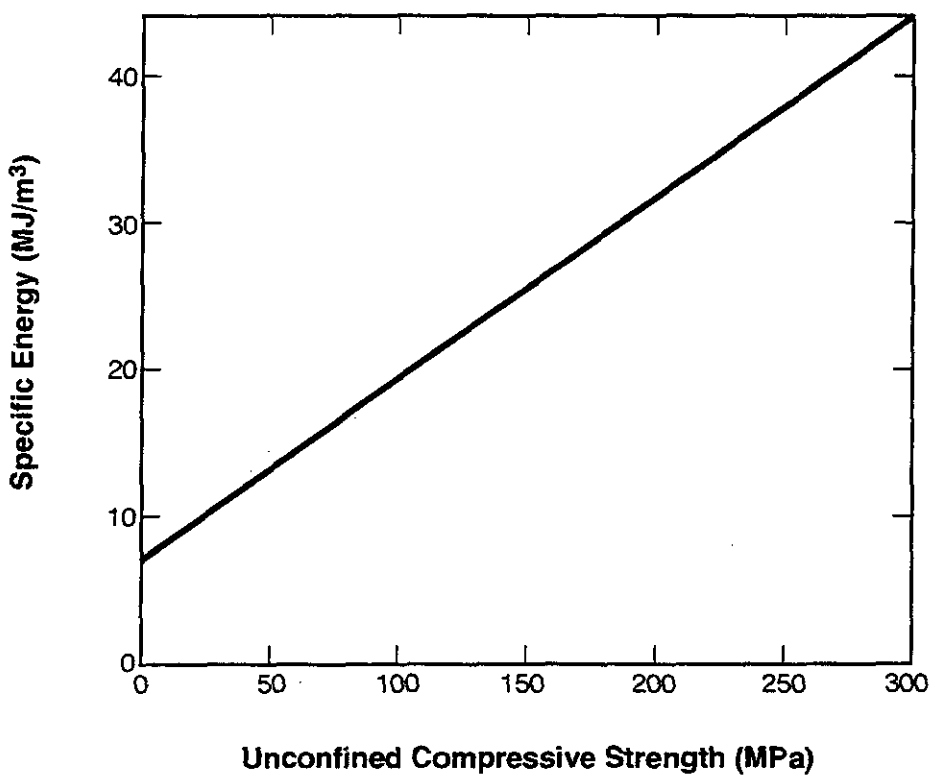


Figure 3-8
Mining Advance Rate Mine Waste Removal Evaluation

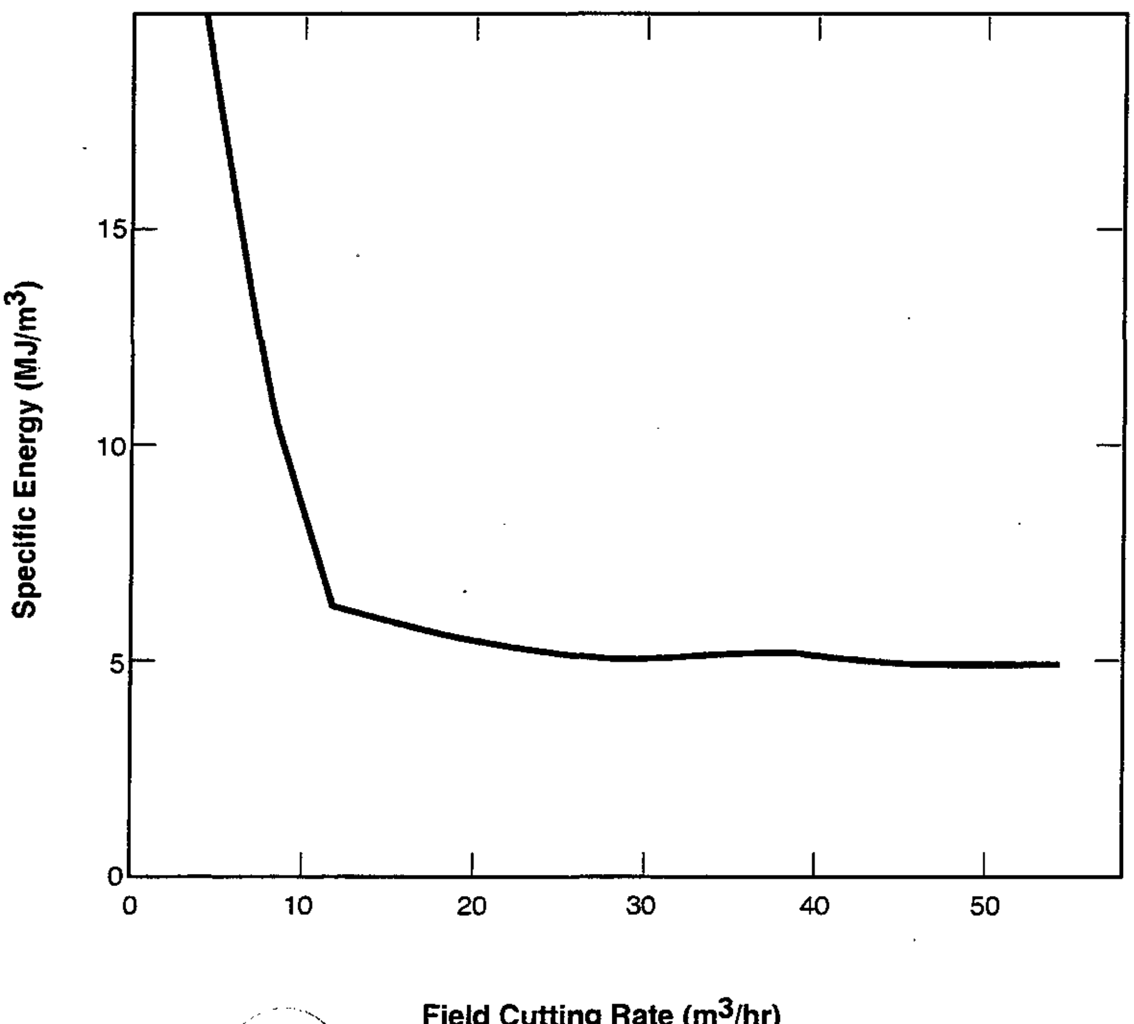


Figure 3-9
Relationship of Specific Energy to the Field Cutting Rate

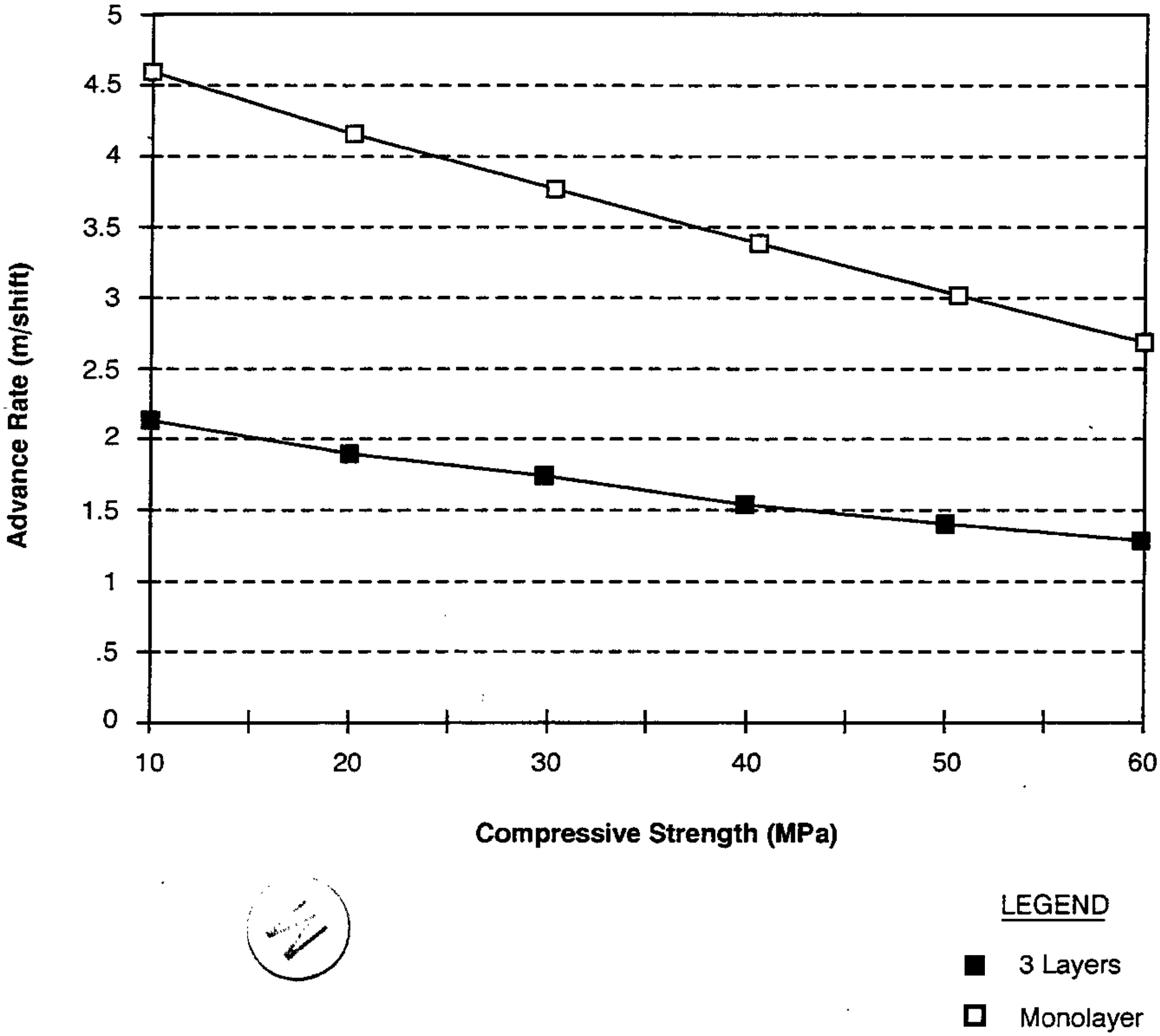


Figure 3-10
Relationship of Mining Advance Rate to Compressive Strength

3.4.3 Assumptions and Data for Factor 4

Data sources for assessing the unconfined compressive strength and the mining advance rate have been described previously. The baseline operational parameters for waste removal is defined by the following assumptions:

- Waste will be placed in the eight panels plus their associated access drifts giving the waste disposal volume of 10 panel equivalents.

- Underground excavation and waste removal occurs at some future time when the waste consolidate to near lithostatic stress after decommissioning and sealing of the facility. Waste recovery is by continuous mining using available technology.

- The underground waste removal activities require continuous mining and re-excavation of the ten equivalent panels. Each panel equivalent will hold approximately 80,000 drums of contact handled waste for a total waste inventory of approximately 800,000 drums. The waste inventory for the baseline consists of sludges, solid organic waste and solid inorganic waste. No backfill is considered, but overexcavation of the waste stack would be necessary to assure complete removal of the waste stack. For purposes of analysis, it is assumed that the dimensions of the rooms excavated equals the initial dimensions. The dimensions of the rooms for the baseline analysis are 13 ft by 33 ft by 300 ft (3.96 by 10.06 by 91.43 m) (Case et al., 1991). There are 12.54 room equivalents per panel, and 10 equivalent panels for all EAs. The WIPP design includes eight panels, with the associated panel access drifts providing an additional two panel equivalents.

- RH TRU waste is not considered in this analysis. The comparison of RH waste baseline with the EAs shows no difference. The analysis of baseline conditions with respect to EA related cost, time, and risk values shows no variability in results.

- Mining advance rates will be developed from the estimated strength and density of the waste forms after consolidation to near lithostatic stress. At this point in time, each waste form will have a certain density and porosity. The porosity is estimated from porosity versus stress relationships developed, and then related to the compressive strength for each waste form. The mining advance rate is inversely proportional to the compressive strength and density of the waste form.

- Performance studies have been performed by the mining industry for mining advance rates using continuous mining equipment relative to various rock types and rock strengths (e.g., McFeat-Smith and Powell, 1979). Mining advance rates at the WIPP will be estimated from these performance studies. Mined waste handling is scheduled at the same rate as excavation. The amount of time required for mining is determined from the panel entry lengths divided by the mining advance rate.

- Following excavation, the CH-TRU waste will be emplaced in waste containers similar to the standard waste boxes used by the project by a Load-Haul-Dump operation. Waste transporters move the material to the ground surface. The material disposition of the waste after this point in time is beyond the scope the EACBS.

- After completion of waste removal activities in a panel, the panel will be closed and isolated from the other panel by the construction of panel ventilation barriers. Underground ventilation will then be established to the next panel for waste removal activities.

- Based upon the above assumptions for underground mining and removal operations, a schedule is developed for waste removal, the number of man hours determined, and the occupational hazards assessed for the removal period. The occupational hazards for industrial accidents include the conventional hazards due to underground mining accidents, hazardous waste exposure during an accident, and radiation exposure during an accident.

For each of the alternatives, additional operational parameters are defined regarding repository geometry, and backfill emplacement. These include:

- For plasma processing with a single layer of drums per room, an initial void space 8.2 ft (2.5 meters) high above the waste stack would exist. This results in the excavation of salt that affects the mining time.

- For the 77 series of EAs involving the monolayer of waste containers, the initial room dimensions are 6 ft X 33 ft X 300 ft (1.83 X 10.06 X 91.44 m).

- The radionuclide inventory per panel remains the same for each of the alternatives. For alternatives involving the 77 and 94 series, less waste is placed per room under this assumption and the WIPP cannot accommodate the total waste inventory.

- The thickness of the backfill layer around the drums is 0.5 m between the room sidewall and the waste stack, and about 2 ft (0.6 m) above the waste stack. The void space between the waste drums is 80 percent for the "wet" backfill alternatives involving grout, and 50 percent for the "dry" backfill alternatives.

The volumes of backfill have been calculated and are presented in Table 3-30. The salt volume excavated to the initial room dimensions considers the total volume for 10 panel equivalents that are mined out equal to 16,138,593 ft^3 (456,938 m^3) for a 13 ft (3.96 m) high drift and 7,448,565 ft^3 (210,894 m^3) for a 6 ft (1.83 m) high drift minus the volume for the waste and the emplaced backfill. The total backfill volume is based on the geometry of the backfill, and the void space.

The average mining advance rate is determined from the average compressive strength in Table 3-29 and the relationships in Figure 3-10 for either the 6 ft (1.83 m) high or the 13 ft (3.96 m) high entry. The number of shifts is determined by the entry length divided by the average mining advance rate (Table 3-31). The subtotal manning table for mining excavation during waste removal is determined by multiplying the number of shifts by 24 with 8 persons working at any given time. The subtotal manning for materials handling during waste removal is determined by the number of workers per shift (assumed to be 30 with 10 working at any given time). The total man hours available for accidents to occur is equal to 18 workers per shift times 8 hours per shift times the number of shifts. The industrial accident estimates are taken from (D'Appolonia Consulting Engineers, Inc., 1976) for salt. The rates are 39.7 injuries per 3.04 million man-hours worked for nonfatal accidents, and 1.97 fatalities per 3.04 million man-hours worked for fatal

TABLE 3-30
SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Backfill Material Volume (m^3)	Backfill Emplaced Volume (m^3)	Salt Volume (m^3)	No. of Panels
0	Baseline	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	0	—	289,814	10
1	Compact Waste	54,389	26,019	13,438	93,846	9,385	45,097	93,846	0	0	—	363,092	10
6	Shred and Compact	54,389	56,498	29,181	140,068	14,007	67,308	140,068	0	0	—	316,870	10
10	Plasma Processing of All Waste	10,767	24,532	12,671	47,970	4,797	23,051	47,970	0	0	—	408,968	10
33	Sand Plus Clay Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	154,500	207,370	82,444	10
35.a	Salt Aggregate Grout Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	186,220	207,370	82,444	10
35.b	Cementitious Grout Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	186,220	207,370	82,444	10
77.a	Supercompact organics and inorganics, salt-aggregate grout backfill, monolayer of 2,000 drums, in 6X33X300	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	109,220	117,000	41,703	10
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2,000 drums, in 6X33X300	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	97,540	117,000	41,703	10
77.c	Supercompact organics and inorganics, sand plus clay based backfill, monolayer of 2,000 drums, in 6X33X300	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	97,540	117,000	41,703	10

Refer to footnotes at end of table.

TABLE 3-30 (Continued)
SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Backfill Material Volume (m^3)	Backfill Emplaced Volume (m^3)	Salt Volume (m^3)	No. of Panels
77.d	Supercompact organics and inorganics, CaO based backfill, monolayer of 2,000 drums, in 6X33X300	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	97,540	117,000	41,703	10
83	Salt Backfill with CaO	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	154,500	207,370	82,444	10
94.a	SPM IT-4 Enhanced cement sludges, shred and add clay organics and inorganics, no backfill	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	0	0	289,814	10
94.b	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, sand plus clay backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	154,500	207,370	82,444	10
94.c	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, cementitious grout backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	186,220	207,370	82,444	10

Refer to footnotes at end of table.

TABLE 3-30 (Continued)
SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Backfill Material Volume (m^3)	Backfill Emplaced Volume (m^3)	Salt Volume (m^3)	No. of Panels
94.d	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	186,220	207,370	82,444	10
94.e	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, clay backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	154,500	207,370	82,444	10
94.f	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, CaO backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	154,500	207,370	82,444	10
111	Clay Based Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	154,500	207,370	82,444	10

*Unaccepted Waste Volume is the volume of waste generated by a treatment process that is in excess of the WIPP design volume.

Source: DOE, 1995e, Baseline Inventory Report, See Appendix O for Waste Inventory Details.

TABLE 3-31
MINING ADVANCE RATE AND TIME

Identifier	Alternative	Average Advance Rate m/shift	No. of Shifts	Mining Excavation Man-Shifts	Materials Handling Man-Shifts	Total Man-Shifts	Man Hours	Fatal Accidents	Nonfatal Accidents
0	Baseline	1.8	6,243	149,835	187,294	337,129	899,010	0.58	11.74
1	Compact Waste	1.8	6,202	148,842	186,052	334,894	893,051	0.58	11.66
6	Shred and Compact	1.8	6,240	149,753	187,192	336,945	898,521	0.58	11.73
10	Plasma Processing of All Waste	1.9	6,177	148,246	185,307	333,553	889,474	0.58	11.62
33	Sand Plus Clay Backfill	2.0	5,710	137,042	171,303	308,345	822,254	0.53	10.74
35.a	Salt Aggregate Grout Backfill	1.9	6,013	144,324	180,404	324,728	865,941	0.56	11.31
35.b	Cementitious Grout Backfill	1.9	6,013	144,324	180,404	324,728	865,941	0.56	11.31
77.a	Supercompact organics and inorganics, salt-aggregate grout backfill, monolayer of 2,000 drums, in 6X33X300	4.2	2,733	65,591	81,988	147,579	393,544	0.26	5.14
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums, in 6X33X300	4.5	2,569	61,648	77,060	138,708	369,887	0.24	4.83
77.c	Supercompact organics and inorganics, sand plus clay based backfill, monolayer of 2,000 drums, in 6X33X300	4.5	2,569	61,648	77,060	138,708	369,887	0.24	4.83
77.d	Supercompact organics and inorganics, CaO based backfill, monolayer of 2,000 drums, in 6X33X300	4.2	2,706	64,952	81,189	146,141	389,709	0.25	5.09
83	Salt Backfill with CaO	1.9	5,965	143,153	178,942	322,095	858,921	0.56	11.22

TABLE 3-31 (Continued)
MINING ADVANCE RATE AND TIME

Identifier	Alternative	Average Advance Rate m/shift	No. of Shifts	Mining Excavation Man-Shifts	Materials Handling Man-Shifts	Total Man-Shifts	Man Hours	Fatal Accidents	Nonfatal Accidents
94.a	Enhanced cement sludges, shred and add clay organics and inorganics, no backfill	1.8	6,215	149,154	186,442	335,596	894,921	0.58	11.69
94.b	Enhanced cement sludges, shred and add clay based material to organics and inorganics, sand plus clay backfill.	2.0	5,686	136,472	170,590	307,062	818,832	0.53	10.69
94.c	Enhanced cement sludges, shred and add clay based material to organics and inorganics, cementitious grout backfill.	1.9	5,987	143,691	179,614	323,305	862,147	0.56	11.26
94.d	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.	1.9	5,987	143,691	179,614	323,305	862,147	0.56	11.26
94.e	Enhanced cement sludges, shred and add clay based material to organics and inorganics, clay backfill.	2.0	5,686	136,472	170,590	307,062	818,832	0.53	10.69
94.f	Enhanced cement sludges, shred and add clay based material to organics and inorganics, CaO backfill.	1.9	5,939	142,531	178,164	320,695	855,188	0.55	11.17
111	Clay Based Backfill	2.0	5,710	137,042	171,303	308,345	822,254	0.53	10.74

accidents. The radiation exposure would be no different between alternatives based upon the assumption that the radionuclide inventory per panel remains the same for each of the alternatives. For hazardous organic materials, plasma processing would eliminate hazardous waste exposure.

3.4.4 Results of Analysis for Factor 4

The results show that among the alternatives, the placement of the waste in a single monolayer in a 6 ft by 33 ft (1.83 by 10.06 m) room would reduce mining excavation substantially, and would reduce the number of underground mining accidents substantially. The results show little difference among the other alternatives since the mining advance rate is nearly the same at 6.56 ft (2 m) per shift for nonmetallic waste, and 3.28 ft (1 m) per shift for metallic waste. The use of clay or sand backfill would exhibit a slightly lower strength, and result in a reduced waste removal time. Yet, these effects are secondary since the waste stack would need to be overexcavated to assure removal of the waste.

3.5 IMPACT ON TRANSPORTATION RISK

Transportation risks are evaluated based on the number of CH- and RH-TRU waste shipments required to dispose of the WIPP authorized waste volume of 6.2 million cubic feet. This provides a reasonably conservative analysis which is consistent with prior waste shipment studies for the WIPP. In general, this volume basis analysis approach involves more shipments than would be required to ship the EA final waste form quantities identified in Table 2-6. Based on estimated final waste form densities, some shipments may be weight limited and may not be able to fully utilize the volume capacity of a TRUPACT-II. With the current level of available information and to meet the objectives of the current study as discussed in Section 1.1, this study retains the use of WIPP's authorized waste volume and the volume capacity of a TRUPACT-II to estimate the number of waste shipments.

Four transportation configurations are considered in the analysis: the baseline and decentralized, regionalized, and centralized configurations. The baseline is defined as shipment of WIPP WAC-certified TRU waste from all generator/storage sites to WIPP (Figure 3-11). In the decentralized case (also shown on Figure 3-11), most waste processing required to enhance repository performance would occur at the generator/storage sites, but some of the small-quantity generators would ship waste to one of the large-quantity generators for processing. In the regionalized case, waste would be shipped to Hanford Site, Idaho National Engineering Laboratory, Savannah River Site, or Los Alamos National Laboratory for processing (Figure 3-12). The centralized case would consist of shipment of all waste from the generator/storage sites to a processing facility located at WIPP (Figure 3-13).

Approximately 98 percent of the CH- and RH-TRU waste shipments will originate from six major generator/storage facilities. The remaining shipments originate from approximately 14 minor facilities. The major/minor facilities, shown on Figures 3-11 through 3-13, are as follows:

Facilities	CH-TRU	RH-TRU
Hanford	Major site	Major site
INEL	Major site	Minor site
LANL	Major site	Minor site
RFETS	Major site	Minor site
SRS	Major site	Minor site
ORNL	Minor site	Major site
AMES	Minor site	Not generated or stored
ANL/E	Minor site	Not generated or stored
Battelle	Not generated or stored	Minor site
Bettis	Minor site	Minor site
ETEC	Minor site	Not generated or stored
KAPL	Minor site	Minor site
LBL	Minor site	Not generated or stored
LLNL	Minor site	Not generated or stored
Mound	Minor site	Not generated or stored
MU	Minor site	Not generated or stored

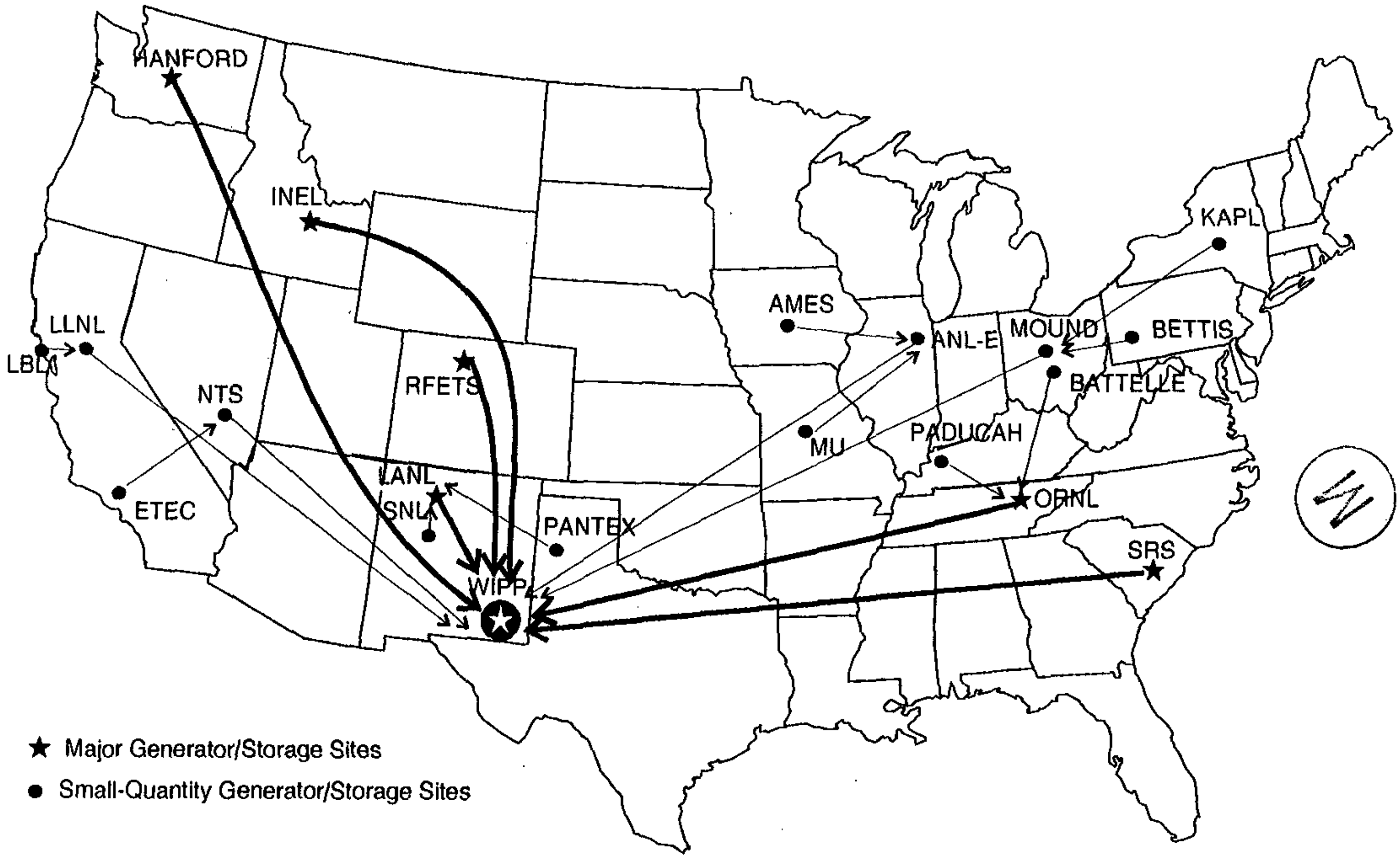


Figure 3-11

Transportation Configuration for Generator/Storage Site Base Case & Decentralized Configuration

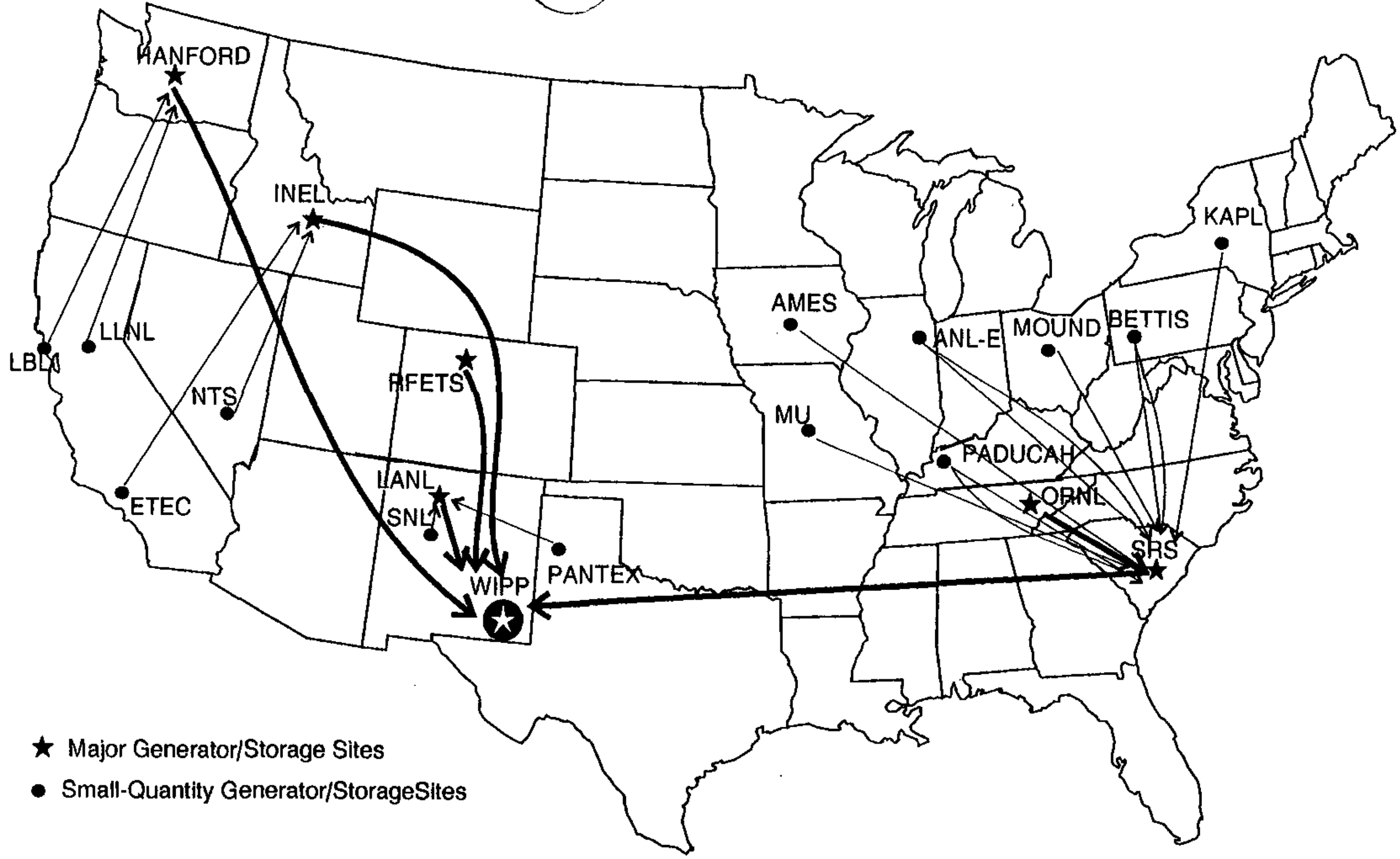


Figure 3-12
Transportation Configuration for Generator/Storage Site Regionalized Configuration

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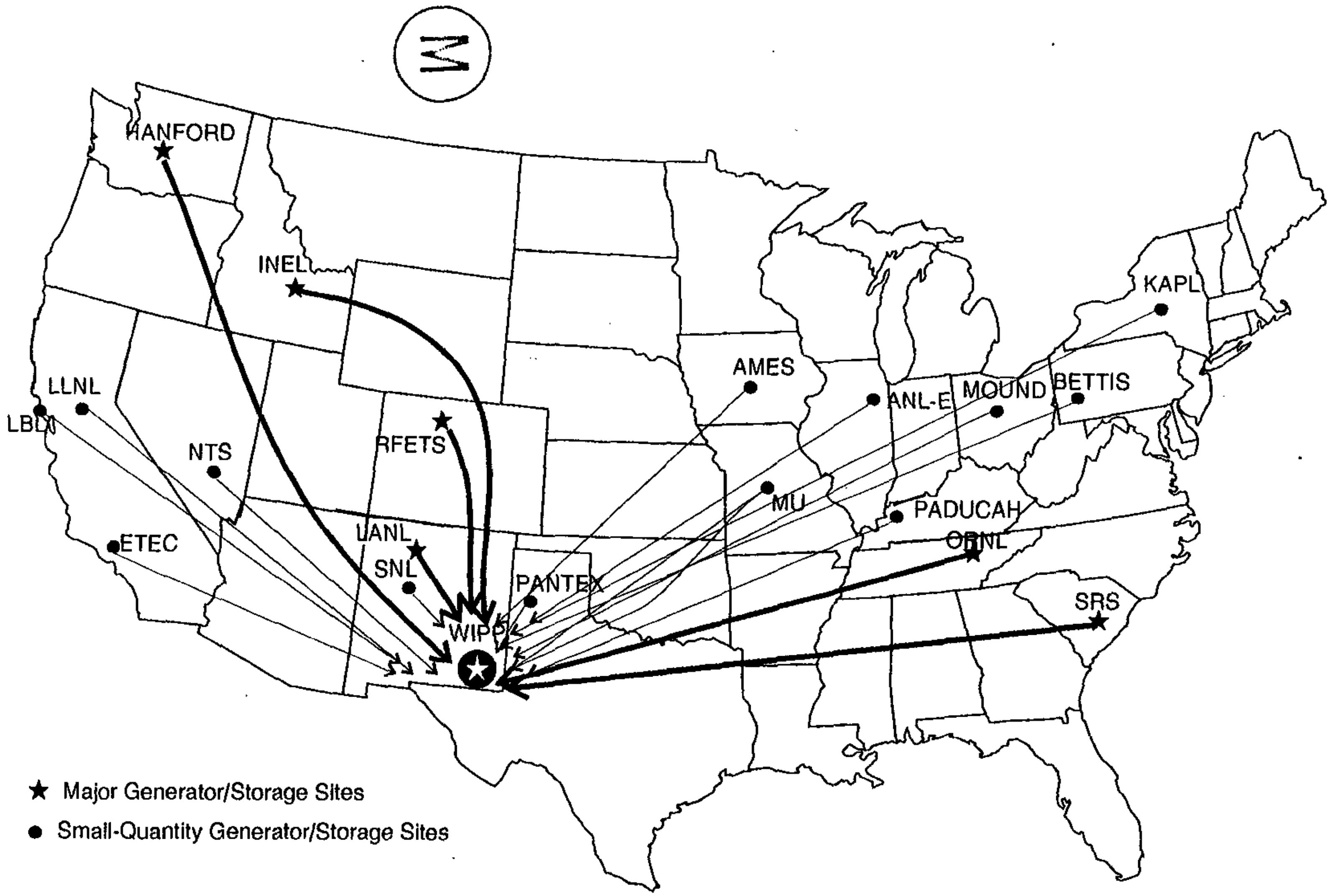

Figure 3-13
Transportation Configuration for Generator/Storage Site Centralized Configuration

DOE/WIPP 95-2135 10/13/95

NTS	Minor site	Not generated or stored
Paducah	Minor site	Not generated or stored
Pantex	Minor site	Not generated or stored
SNL	Minor site	Not generated or stored

The engineered alternatives that are being analyzed for their impact on transportation risk are:

No. 1: Compact waste

No. 6: Shred and compact

No. 10: Plasma processing

No. 77: Supercompact organics and inorganics (solid waste)

No. 94: Enhanced cementation of sludges, shred and add clay based materials to organics and inorganics.

All CH- and RH-TRU waste that is transported either for processing or disposal will be shipped in Type B transportation packages. CH-TRU waste will be placed either in 55-gallon (208-liter) drums or standard waste boxes (SWBs) and transported in a Transuranic Package Transporter-II (TRUPACT-II) (Figure 3-14). RH-TRU waste will be in either 30-gallon (113.6-liter) or 55-gallon (208-liter) drums placed in a RH-TRU waste canister and transported in an RH-72B cask. The TRUPACT-II has been certified by the U.S. Nuclear Regulatory Commission (NRC) and has been used by the DOE for intrasite CH-TRU waste transportation. The RH-72B cask (Figure 3-15) has yet to be NRC certified, but is scheduled to be available for RH-TRU waste transportation when WIPP is ready for waste emplacement.

3.5.1 Definition of the TRU Waste Transportation Risk Factor

The transportation risk factor consists of the human health impacts that could potentially result from transporting CH- or RH-TRU waste. The risk factor is defined in terms of the radiological, chemical, and non-radiological/non-chemical impacts of either normal, incident-free transportation or transportation accidents.

3.5.2 Methodology Used to Evaluate the Transportation Risk Factor

The transportation analysis presented in this chapter was conducted similarly to assessments such as NUREG-0170 (NRC, 1977), the WIPP FEIS (DOE, 1980), the WIPP FSEIS (DOE, 1990b), and the Comparative Study of Waste Isolation Pilot Plant (WIPP) Transportation Alternatives (DOE, 1994a). Since 1980, computer models and basic assumptions have been refined, but the approach to estimating the consequences and risks has remained the same. This methodology has proven to be accurate, reliable, and technically acceptable. The analytical codes or models used for this analysis have been extensively documented in the WIPP FSEIS (DOE, 1990b). Methods and assumptions used are provided in the following subsections.

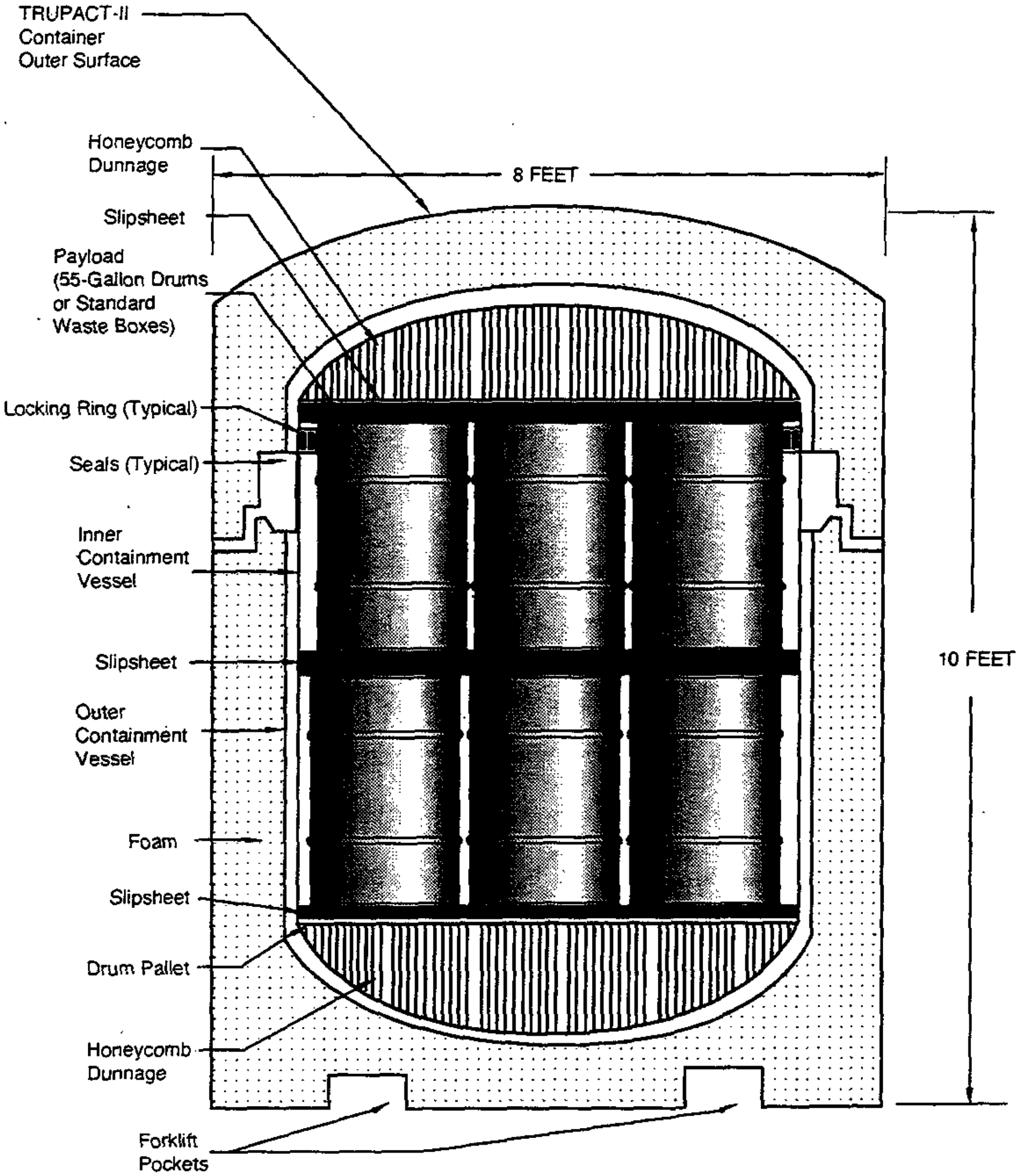

Figure 3-14
TRUPACT-II Shipping Container For CH-TRU Waste (Schematic)

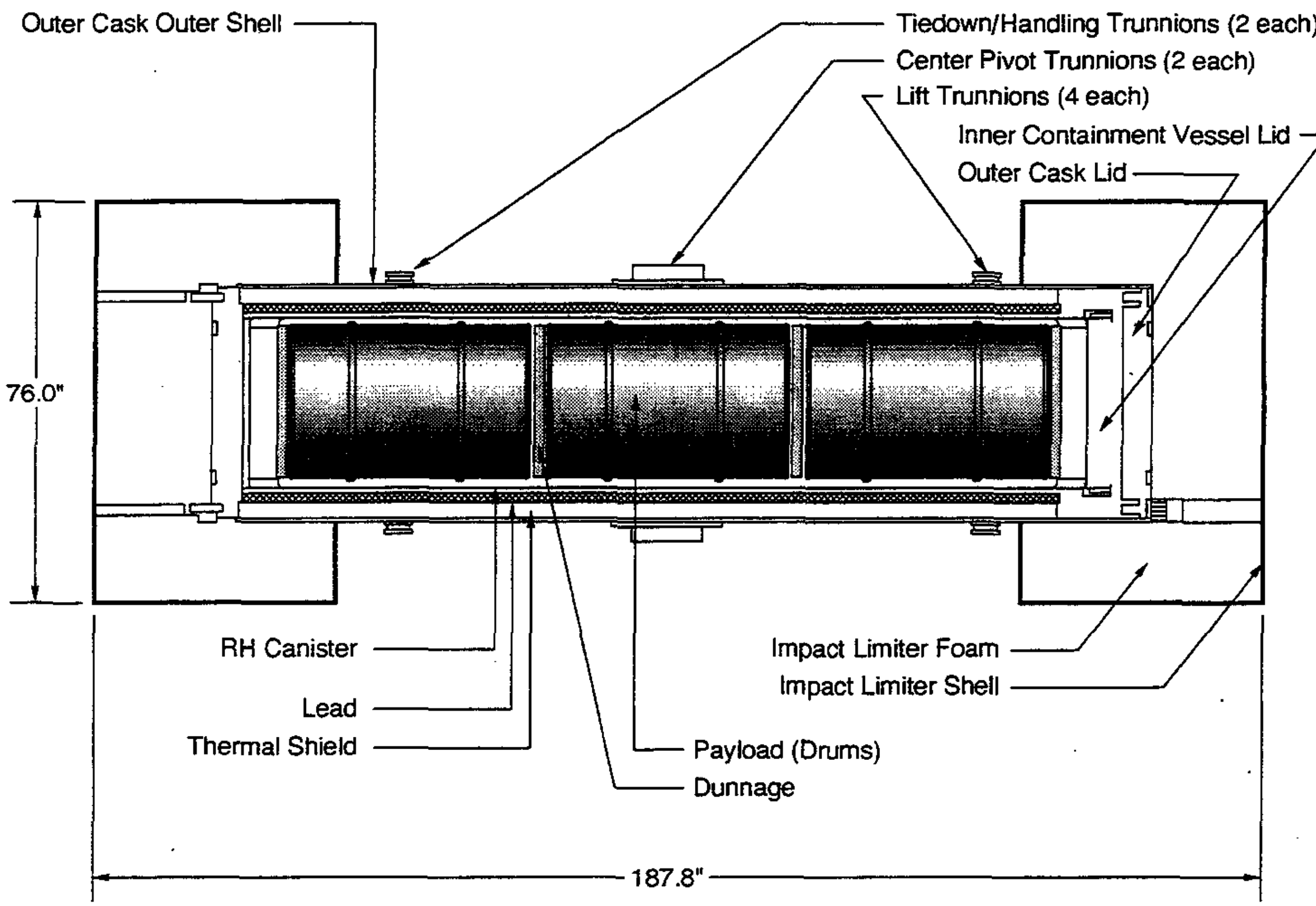

Figure 3-15
RH-72B Shipping Cask for RH-TRU Waste (Schematic)

3.5.2.1 Evaluation Methods Used

3.5.2.1.1 Transportation Routes

The CH- and RH-TRU waste shipments will travel routes as specified in 49 CFR 177.825, which regulates highway and state-approved non-interstate segments between shipment origin sites and the WIPP. Tables 3-32 through 3-35 present origin/destination, total one-way mileage, and fraction of travel in various population zones. These tables also summarize the number of shipments for the transportation configurations for each engineered alternative considered.

3.5.2.1.2 Radiological Exposures

The RADTRAN computer code was used to calculate radiological risks. RADTRAN was originally developed by Sandia National Laboratories to support preparation of NUREG-0170, Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes (NRC, 1977). This code has undergone over 18 years of development and is continuing to be refined. RADTRAN 4 (version 4.0.17) (Neuhauser and Kanipe, 1992) was used for the current analyses and was accessed using TRANSNET, an SNL/NM centralized MICRO VAX II computer system. The TRANSNET system incorporates transportation models and data bases that may be accessed via a modem-equipped personal computer.

RADTRAN calculates doses for various population subgroups (e.g., workers, the public) for normal transportation conditions. For the public, it calculates doses to people

- In the vicinity of the transportation vehicle while it is stopped
- Surrounding the transportation route
- Sharing the transportation route with the vehicle.

The dose assessment incorporates a point-source approximation for distances between the receptor and the source of more than twice the largest physical dimension of the source. A line-source approximation is applied for exposure distances less than twice the largest package dimension. The RADTRAN code incorporates features to take credit for shielding for typical structures in urban and suburban settings. RADTRAN also calculates a hypothetical maximum exposure to an individual who resides along the surface transportation route. The model assumes that the individual lives approximately 100 feet (30 meters) from the surface transportation link and that the vehicle passes by at approximately 40 miles per hour (64 kilometers per hour). RADTRAN incorporates algorithms to predict radiological impacts from accidents exceeding transportation package performance conditions. The code evaluates both internal exposure pathways (i.e., inhalation, resuspension, and ingestion) and external exposure pathways (i.e., cloudshine, groundshine) to project potential accident consequences and risks (probability x consequence) to the general public.

Low levels of penetrating radiation from radioactive material shipments pose an external exposure pathway to transportation workers and the public during normal (incident-free) transportation conditions. Shipment external radiation levels are regulated by the U.S. Department of Transportation (DOT) and the NRC on the basis of the Transport Index (TI). The TI represents

1 **TABLE 3-32**

NUMBER OF SHIPMENTS AND MILEAGE FOR CH-TRU WASTE BASELINE

Waste Origin Site	To Route Destination	Total[1] Shipments	Rural	Suburban	Urban	Total One-Way Mileage
Major CH-TRU Waste Sites						
HANFORD	WIPP	5,712	1,645.3	144.4	18.1	1,808.0
INEL	WIPP	4,974	1,262.5	114.1	15.4	1,392.0
LANL	WIPP	2,839[2]	318.4	21.4	2.1	342.0
RFETS	WIPP	931	618.6	71.1	14.1	704.0
SRS	WIPP	2,827	1,184.2	304.8	19.8	1,509.0
Small CH-TRU Waste Sites						
AMES	ANL-E	1	300.7	50.2	2.1	353.0
ANL-E	WIPP	7[3]	1,237.7	203.0	13.8	1,455.0
BETTIS	MOUND	17	155.0	113.8	20.0	289.0
ETEC	NTS	2	269.1	61.3	44.6	375.0
KAPL	MOUND	1	381.8	291.2	20.6	694.0
LBL	LLNL	1	19.9	31.8	23.2	75.0
LLNL	WIPP	137[4]	1,303.6	100.4	47.9	1,452.0
MOUND	WIPP	47[5]	1,301.3	234.3	20.8	1,557.0
MU	ANL-E	1	294.8	89.0	9.2	393.0
NTS	WIPP	68[6]	1,136.7	63.8	13.4	1,214.0
ORNL	WIPP	120[7]	1,317.6	182.1	21.1	1,521.0
PADUCAH	ORNL	1	251.0	61.7	4.4	317.0
PANTEX	LANL	1	314.2	16.9	3.8	335.0
SNL	LANL	3	82.1	16.7	5.2	104.0
TOTAL SHIPMENTS		17,690				

[1]The total number of shipments is based on 60% of the waste being shipped in 55-gallon (208-liter) drums and 40% of the waste being shipped in standard waste boxes. It is also assumed that any site with three or less shipments will make all shipments in 55-gallon (208-liter) drums.
[2]This total includes one shipment from PANTEX to LANL and three shipments from SNL to LANL.
[3]This total includes one shipment from AMES to ANL-E and one shipment from MU to ANL-E.
[4]This includes one shipment from LBL.
[5]This total includes 17 shipments from BETTIS to MOUND and one shipment from KAPL to MOUND.
[6]This total includes two shipments from ETEC.
[7]This total includes one shipment from PADUCAH.

Source: Waste Quantity Throughput and Shipments from Wagner, 1995; mileage data from the Highway Computer Code, Johnson et al., 1993.

1 **TABLE 3-33**

NUMBER OF SHIPMENTS AND MILEAGE FOR RH-TRU WASTE BASELINE AND DECENTRALIZED CONFIGURATION

Waste Origin Site	To Route Destination	Total Shipments	Rural	Suburban	Urban	Total One-Way Mileage
Major RH-TRU Waste Sites						
HANFORD	WIPP	5,176	1,645.3	144.4	18.1	1,808.0
ORNL	WIPP	2,185[1]	1,317.6	182.1	21.1	1,521.0
Small RH-TRU Waste Sites						
BATTELLE	ORNL	123	242.6	151.4	14.9	409.0
BETTIS	ORNL	3	414.2	180.1	12.6	607.0
INEL	WIPP	109	1,262.5	114.1	15.4	1,392.0
KAPL	ORNL	57	588.6	285.5	9.8	884.0
LANL	WIPP	249	318.4	21.4	2.1	342.0
SRS	WIPP	56	1,184.2	304.8	19.8	1,509.0
TOTAL SHIPMENTS		7,958				

[1]Total includes 123 shipments from Battelle to ORNL, 3 shipments from Bettis to ORNL, and 57 shipments from KAPL to ORNL.

Source: Waste Quantity Throughput and Shipments from Wagner, 1995; mileage data from the Highway Computer Code, Johnson et al., 1993.

1

TABLE 3-34

NUMBER OF SHIPMENTS AND MILEAGE FOR CH-TRU WASTE REGIONAL CONFIGURATION

Waste Origin Site	Route Destination	Total[1] Shipments	Rural	Suburban	Urban	Total One-Way Mileage
Major CH-TRU Waste Sites						
HANFORD	WIPP	5,849[2]	1,645.3	144.4	18.1	1,808
INEL	WIPP	5,042[3]	1,262.5	114.1	15.4	1,392
LANL	WIPP	2,839[4]	318.4	21.4	2.1	342
RFETS	WIPP	931	618.6	71.1	14.1	704
SRS	WIPP	3,001[5]	1,184.2	304.8	19.8	1,509
Small CH-TRU Waste Sites						
AMES	SRS	1	881.9	292.3	15.7	1,190
ANL-E	SRS	5	587.3	265.9	23.7	877
BETTIS	SRS	17	485	188.4	12.4	686
ETEC	INEL	2	754.7	141.5	61.7	958
KAPL	SRS	1	641.3	295.2	11.7	949
LBL	HANFORD	1	667.7	167.1	35.2	870
LLNL	HANFORD	136	675.1	183.9	30.8	890
MOUND	SRS	29	424.2	206.4	10.4	641
MU	SRS	1	604.3	231.3	27.2	863
NTS	INEL	66	600.3	92.3	20.3	713
ORNL	SRS	119	244.6	110.4	3	358
PADUCAH	SRS	1	380.1	171.1	17.6	569
PANTEX	LANL	1	314.2	16.9	3.8	335
SNL	LANL	3	82.1	16.7	5.2	104
	TOTAL SHIPMENTS	18,045				

[1]The total number of shipments is based on 60% of the waste being shipped in 55-gallon (208-liter) drums and 40% of the waste being shipped in Standard Waste Boxes. It is also assumed that any site with three or less shipments *will make all shipments in 55-gallon (208-liter) drums.*
[2]This total includes 136 shipments from LLNL to HANFORD and one shipment from LBL to HANFORD.
[3]This total includes 66 shipments from NTS to INEL and two shipments from ETEC to INEL.
[4]This total includes one shipment from PANTEX to LANL and three shipments from SNL to LANL.
[5]This total includes five shipments from ANL-E to SRS; one shipment from AMES to SRS; 17 shipments from BETTIS to SRS; one shipment from KAPL to SRS; 20 shipments from MOUND to SRS; one shipment from MU to SRS; 119 shipments from ORNL to SRS; one shipment from PADUCH to SRS.

Source: Waste Quantity Throughput and Shipments from Wagner, 1995; mileage data from the Highway Computer Code, Johnson et al., 1993.

1 **TABLE 3-35**

NUMBER OF SHIPMENTS AND MILEAGE FOR CH-TRU WASTE CENTRALIZED CONFIGURATION

Waste Origin Site	Route Destination	Total[1] Shipments	Rural	Suburban	Urban	Total One-Way Mileage
Major CH-TRU Waste Sites						
HANFORD	WIPP	5,712	1,645.3	144.4	18.1	1,808.0
INEL	WIPP	4,974	1,262.5	114.1	15.4	1,392.0
LANL	WIPP	2,835	318.4	21.4	2.1	342.0
RFETS	WIPP	931	618.6	71.1	14.1	704.0
SRS	WIPP	2,827	1,184.2	304.8	19.8	1,509.0
Small CH-TRU Waste Sites						
AMES	WIPP	1	1,121.4	117.8	15.7	1,255.0
ANL-E	WIPP	5	1,237.7	203.0	13.8	1,455.0
BETTIS	WIPP	17	1,452.7	318.3	31.4	1,803.0
ETEC	WIPP	2	754.7	141.5	61.7	958
KAPL	WIPP	1	1,679.6	495.7	31.9	2,208.0
LBL	WIPP	1	1,320.2	130.5	71.0	1,522.0
LLNL	WIPP	136	1,303.6	100.4	47.9	1,452.0
MOUND	WIPP	29	1,301.3	234.3	20.8	1,557.0
MU	WIPP	1	1,017.5	109.5	17.9	1,145.0
NTS	WIPP	66	1,136.7	63.8	13.4	1,214.0
ORNL	WIPP	119	1,317.6	182.1	21.1	1,521.0
PADUCAH	WIPP	1	1,174.1	171.4	13.9	1,360.0
PANTEX	WIPP	1	412.6	26.7	3.6	443.0
SNL	WIPP	3	288.3	18.7	3.9	311.0
	TOTAL SHIPMENTS	17,662				

[1]The total number of shipments is based on 60% of the waste being shipped in 55-gallon (208-liter) drums and 40% of the waste being shipped in Standard Waste Boxes. It is also assumed that any site with three or less shipments will make all shipments in 55-gallon (208-liter) drums.

Source: Wagner, 1995, mileage data from the Highway Computer Code, Johnson et al., 1993.

the radiation dose rate (in mrem/hr) at 3.3 feet (1 meter) from the surface of the shipping package. Calculated TI values are dependent on:

- Distribution and quantity of radionuclides per shipment
- Self-shielding characteristics of the waste
  - Waste configuration
  - Bulk density
  - Whole-atom ratios of chemical composition
- Configuration and shielding characteristics of the shipment packages.

Calculated TI values are key inputs to the RADTRAN code to evaluate normal transportation impacts.

Shipment TI values were determined using the Microshield Code (Version 3.13, Groves Engineering Inc.) Microshield incorporates libraries of radionuclide kinetics and energies, material absorption coefficients, buildup factors, and dose integration options. TI values were calculated using a cylindrical source/shield model. The calculations took credit for the shelf-shielding characteristics of the waste and for the packaging design. While the TRUPACT-II is not designed specifically to provide shielding, its materials of construction provide some shielding benefits. Pacific Nuclear Systems Dwg No. 2077-500SNP (Rev. K) was used to establish the packaging configuration and material thickness (NRC, 1994). The RH-72B cask is designed to provide shielding and was modeled using Pacific Nuclear Systems Dwg No. X-106-500SNP (Rev. none).

Other key inputs to assess normal transportation impacts are the shipment route length and the fraction of travel in urban, suburban, and rural zones. These zones were determined using the HIGHWAY model (Johnson et al., 1993). Routes were selected for analysis based on 49 CFR 177.825, for truck, which regulates highways and state-approved, non-interstate segments between the shipment origin sites and the WIPP. Exposures to individuals residing or working in buildings along the route were determined using RADTRAN Shielding Option 2. This option estimates exposures to individuals in buildings at reduced rates and takes representative credit for shielding benefits afforded by typical building structures found in the three population areas.

Primary RADTRAN input parameters are summarized in Table 3-36 and are representative of CH-TRU and RH-TRU waste truck shipment modes analyzed in this study. Route-specific population densities were used as determined by the HIGHWAY model. Calculated TRU waste truck shipment TI values are presented in Table 3-37 and were estimated using the Microshield code as discussed above. For engineered alternatives and system configurations requiring waste processing at another location, the TI for the origin/treatment location route segment differs from the TI for the treatment location/WIPP route segment, as determined by how the treatment process affects the final waste form mass (kg/m^3) and radionuclide (Ci/m^3) densities. Radionuclides evaluated and their associated RADTRAN input parameters are summarized in Table 3-38.

A screening analysis was performed to select the radionuclides for evaluation, as summarized in Table 3-38. The BIR identifies approximately 139 radionuclides in the WIPP disposal inventory

1 **TABLE 3-36**

RADTRAN INPUT DATA

Parameter	CH-TRU Waste	RH-TRU Waste
Configuration Data		
Transport Mode	Truck	Truck
Package Type	TRUPACT-II	72B Cask
Packages/Shipment	3[1]	1
Package Characteristic Dimension, m	7.39	3.6
Movement Data		
Shipment distance, km	(site/alternative-specific)	
Population density, people/km	(route/alternative-specific per Highway Routing Model)	
Shipment speed, km/hr		
- Urban population zone	24.16	24.16
- Suburban population zone	40.32	40.32
- Rural population zone	88.56	88.56
Stop time per kilometer, hr/km	0.011	0.011
Other normal input	(RADTRAN 4 default values)	
Normal Exposure Data		
Transport Index (TI), mrem/hr	(site/alternative-specific, see Table 3-37)	
Number of crew members	2	2
Effective distance from source to crew,[2]	10	19
Number of people per public vehicle	2	2
Number of people exposed while stopped	50	50
Exposure distance while stopped, m	20	20
Accident Exposure Data		
Number of accident severity categories[3]	8	8
Accident severity category frequency	(NUREG-0170 values)	
Radioactive contents/parameters	(see Table 3-38)	
Release fractions	(See Table 3-39)	
Other accident inputs	(RADTRAN 4 and default values)	
Accident rates,[4] accidents/km		
- Urban population zone	1.60×10^{-05}	1.60×10^{-05}
- Suburban population zone	3.00×10^{-06}	3.00×10^{-06}
- Rural population zone	1.37×10^{-07}	1.37×10^{-07}

[1]Treated in RADTRAN model as one effective package.
[2]Accounts for RADTRAN simplified exposure model.
[3]Based on NUREG-0170, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes" (NRC, 1977).
[4]Based on *Comparative Study of Waste Isolation Pilot Plant (WIPP) Transportation Alternatives* (DOE, 1994a).

TABLE 3-37

CALCULATED TRU WASTE TRUCK SHIPMENT TI VALUES[1,2,3,4]

Waste Origin Site	To Route Segment Destination	CH-TRU					RH-TRU
		Baseline	Alternative No. 1 & 77	Alternative No. 6	Alternative No. 10	Alternative No. 94	Baseline
AMES	ANL-E	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	
	SRS		$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	
	WIPP	$1.0\times10^{+00}$	9.0×10^{-01}	8.7×10^{-01}	$1.2\times10^{+00}$	5.1×10^{-01}	
ANL-E	SRS		1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	
BATTELLE	ORNL						3.8×10^{-01}
	WIPP						3.8×10^{-01}
BETTIS	MOUND	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	
	ORNL						3.2×10^{-01}
	SRS		$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	
	WIPP	$1.0\times10^{+00}$	9.0×10^{-01}	8.7×10^{-01}	$1.2\times10^{+00}$	5.1×10^{-01}	3.2×10^{-01}
ETEC	INEL		$5.6\times10^{+00}$	$5.6\times10^{+00}$	$5.6\times10^{+00}$	$5.6\times10^{+00}$	
	NTS	$5.6\times10^{+00}$	$5.6\times10^{+00}$	$5.6\times10^{+00}$	$5.6\times10^{+00}$	$5.6\times10^{+00}$	
	WIPP	$5.6\times10^{+00}$	$1.3\times10^{+01}$	$7.4\times10^{+00}$	$1.4\times10^{+01}$	$1.0\times10^{+01}$	
HANFORD	WIPP	$9.3\times10^{+00}$	$8.0\times10^{+00}$	$7.5\times10^{+00}$	$9.8\times10^{+00}$	$5.9\times10^{+00}$	$6.9\times10^{+01}$
INEL	WIPP	$1.0\times10^{+00}$	9.0×10^{-01}	8.7×10^{-01}	$1.2\times10^{+00}$	5.1×10^{-01}	$2.4\times10^{+00}$
KAPL	MOUND	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	
	ORNL						7.1×10^{-01}
	SRS		$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	
	WIPP	$1.0\times10^{+00}$	9.0×10^{-01}	8.7×10^{-01}	$1.2\times10^{+00}$	5.1×10^{-01}	7.1×10^{-01}
LANL	WIPP	4.8×10^{-01}	6.8×10^{-01}	6.6×10^{-01}	$1.0\times10^{+00}$	4.3×10^{-01}	$1.3\times10^{+00}$
LBL	HANFORD		1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	LLNL	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	

Refer to footnotes at end of table.

1 **TABLE 3-37 (Continued)**

CALCULATED TRU WASTE TRUCK SHIPMENT TI VALUES[1,2,3,4]

Waste Origin Site	To Route Segment Destination	CH-TRU Baseline	CH-TRU Alternative No. 1 & 77	CH-TRU Alternative No. 6	CH-TRU Alternative No. 10	CH-TRU Alternative No. 94	RH-TRU Baseline
	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	
LLNL	HANFORD		1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	
MOUND	SRS		1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	
MU	ANL-E	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	SRS		1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	
NTS	INEL		$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	$1.0\times10^{+00}$	
	WIPP	$1.0\times10^{+00}$	9.0×10^{-01}	8.7×10^{-01}	$1.2\times10^{+00}$	5.1×10^{-01}	
ORNL	SRS		$2.2\times10^{+02}$	$2.2\times10^{+02}$	$2.2\times10^{+02}$	$2.2\times10^{+02}$	
	WIPP	$2.2\times10^{+02}$	$1.1\times10^{+02}$	$1.3\times10^{+02}$	$1.2\times10^{+02}$	$6.9\times10^{+01}$	$2.0\times10^{+01}$
PA	ORNL	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	SRS		1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	
PANTEX	LANL	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	
RFETS	WIPP	1.3×10^{-02}	9.3×10^{-03}	9.2×10^{-03}	1.8×10^{-02}	7.8×10^{-03}	
SNL	LANL	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	1.0×10^{-02}	
	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	
SRS	WIPP	1.0×10^{-02}	1.1×10^{-02}	1.0×10^{-02}	1.2×10^{-02}	7.7×10^{-03}	$1.6\times10^{+01}$

[1]Tabulated TI values have units of mrem/hr.
[2]Tablulated shipment TI values for route segments to treatment/storage considered under the decentralized and regional treatment configuration are the same as the baseline values.
[3]Tablulated shipment TI values for the WIPP route segments are for the treated waste forms considered under the respective engineered alternatives.
[4]Shipment TI values to WIPP under the centralized treatment configuration are the same as the baseline values for all engineered alternatives.

1 **TABLE 3-38**

SELECTED RADIONUCLIDES FOR TRANSPORTATION ANALYSIS AND ASSOCIATED RADTRAN INPUTS

Radionuclide	Half-life (days)	Photon Energy (MeV)	Cloudshine Dose Factor (rem-m^3/Ci-sec)	Inhalation Dose Factor (rem CEDE/Ci)	Lung Type	1-yr Lung Dose for Inhalation (rem/Ci)	1-yr Marrow Dose for Inh (rem/Ci)
AC-227	$7.29\times10^{+03}$	2.31×10^{-04}	1.99×10^{-05}	$7.70\times10^{+09}$	3	$2.30\times10^{+09}$	$4.30\times10^{+08}$
AM-241	$1.58\times10^{+05}$	3.24×10^{-02}	3.01×10^{-03}	$5.90\times10^{+08}$	3	$1.20\times10^{+08}$	$1.70\times10^{+07}$
AM-243	$2.70\times10^{+06}$	5.59×10^{-02}	8.11×10^{-03}	$5.90\times10^{+08}$	3	$1.10\times10^{+08}$	$1.60\times10^{+07}$
BA-137m	Accounted for by RADTRAN with parent nuclide (CS-137)						
CE-144	$2.84\times10^{+02}$	5.25×10^{-02}	2.88×10^{-03}	$6.30\times10^{+05}$	1	$3.60\times10^{+06}$	$4.20\times10^{+03}$
CF-252	$9.64\times10^{+02}$	1.20×10^{-03}	1.19×10^{-05}	$2.40\times10^{+08}$	3	$8.60\times10^{+08}$	$2.30\times10^{+06}$
CM-243	$1.04\times10^{+04}$	1.34×10^{-01}	2.02×10^{-02}	$4.00\times10^{+08}$	3	$1.20\times10^{+08}$	$1.70\times10^{+07}$
CM-244	$6.62\times10^{+03}$	1.70×10^{-03}	1.33×10^{-05}	$3.10\times10^{+08}$	3	$1.20\times10^{+08}$	$1.70\times10^{+07}$
CM-245	$3.10\times10^{+06}$	9.55×10^{-02}	1.13×10^{-02}	$6.20\times10^{+08}$	3	$1.10\times10^{+08}$	$1.60\times10^{+07}$
CO-60	$1.93\times10^{+03}$	$2.50\times10^{+00}$	4.12×10^{-01}	$2.80\times10^{+05}$	2	$7.90\times10^{+05}$	$3.80\times10^{+04}$
CS-134	$7.53\times10^{+02}$	$1.55\times10^{+00}$	2.54×10^{-01}	$4.60\times10^{+04}$	2	$4.10\times10^{+04}$	$3.90\times10^{+04}$
CS-137	$1.10\times10^{+04}$	5.96×10^{-01}	$0.00\times10^{+00}$	$3.20\times10^{+04}$	2	$3.10\times10^{+04}$	$2.60\times10^{+04}$
EU-152	$4.87\times10^{+03}$	$1.14\times10^{+00}$	1.87×10^{-01}	$2.60\times10^{+05}$	2	$0.00\times10^{+00}$	$0.00\times10^{+00}$
EU-154	$3.21\times10^{+03}$	$1.22\times10^{+00}$	2.06×10^{-01}	$3.10\times10^{+05}$	2	$0.00\times10^{+00}$	$0.00\times10^{+00}$
EU-155	$1.81\times10^{+03}$	6.05×10^{-02}	9.10×10^{-03}	$4.80\times10^{+04}$	2	$0.00\times10^{+00}$	$0.00\times10^{+00}$
NB-95	$3.52\times10^{+01}$	7.66×10^{-01}	1.26×10^{-01}	$7.30\times10^{+03}$	1	$5.30\times10^{+04}$	$2.40\times10^{+03}$
NP-237	$7.82\times10^{+08}$	3.43×10^{-02}	3.64×10^{-03}	$5.60\times10^{+08}$	3	$1.00\times10^{+08}$	$1.50\times10^{+07}$
PR-144	Accounted for by RADTRAN with parent nuclide (CE-144)						
PU-238	$3.21\times10^{+04}$	1.81×10^{-03}	1.40×10^{-05}	$5.30\times10^{+08}$	3	$4.50\times10^{+08}$	$1.10\times10^{+06}$
PU-239	$8.79\times10^{+06}$	7.96×10^{-04}	1.30×10^{-05}	$5.70\times10^{+08}$	3	$4.20\times10^{+08}$	$1.10\times10^{+06}$
PU-240	$2.39\times10^{+06}$	1.73×10^{-03}	1.37×10^{-05}	$5.70\times10^{+08}$	3	$4.20\times10^{+08}$	$1.10\times10^{+06}$
PU-241	$5.26\times10^{+03}$	2.54×10^{-06}	0.00×10^{-00}	$9.90\times10^{+06}$	3	$3.60\times10^{+05}$	$1.30\times10^{+03}$
PU-242	$1.37\times10^{+08}$	1.44×10^{-03}	1.16×10^{-05}	$5.30\times10^{+08}$	3	$4.00\times10^{+08}$	$1.00\times10^{+06}$
RH-106	3.46×10^{-04}	2.01×10^{-01}	3.33×10^{-02}	$2.20\times10^{+00}$	1	$4.30\times10^{+06}$	$4.00\times10^{+04}$
SB-125	$1.01\times10^{+03}$	4.30×10^{-01}	6.75×10^{-02}	$1.70\times10^{+04}$	2	$4.40\times10^{+04}$	$5.50\times10^{+02}$

1 **TABLE 3-38 (Continued)**

SELECTED RADIONUCLIDES FOR TRANSPORTATION ANALYSIS AND ASSOCIATED RADTRAN INPUTS

Radionuclide	Half-life (days)	Photon Energy (MeV)	Cloudshine Dose Factor (rem-m^3/Ci-sec)	Inhalation Dose Factor (rem CEDE/Ci)	Lung Type	1-yr Lung Dose for Inhalation (rem/Ci)	1-yr Marrow Dose for Inh (rem/Ci)
SR-90	$1.06\times10^{+04}$	$0.00\times10^{+00}$	$0.00\times10^{+00}$	$2.40\times10^{+06}$	2	$4.50\times10^{+06}$	$3.80\times10^{+03}$
TE-125m	$5.80\times10^{+01}$	3.55×10^{-02}	1.53×10^{-03}	$1.00\times10^{+04}$	1	$0.00\times10^{+00}$	$0.00\times10^{+00}$
TH-228	$6.98\times10^{+02}$	3.03×10^{-03}	3.14×10^{-04}	$5.80\times10^{+08}$	3	$2.20\times10^{+09}$	$1.20\times10^{+08}$
TH-229	$2.68\times10^{+06}$	9.54×10^{-02}	1.37×10^{-02}	$2.90\times10^{+09}$	3	$2.40\times10^{+09}$	$1.40\times10^{+08}$
TH-231	$1.06\times10^{+00}$	2.55×10^{-02}	1.85×10^{-03}	$1.00\times10^{+03}$	1	$5.10\times10^{+03}$	$6.70\times10^{+01}$
TL-208	2.13×10^{-03}	$3.36\times10^{+00}$	6.28×10^{-01}	$8.00\times10^{+00}$	1	$5.70\times10^{+01}$	$1.10\times10^{+00}$
U-232	$2.63\times10^{+04}$	2.19×10^{-03}	4.22×10^{-05}	$1.10\times10^{+09}$	3	$8.30\times10^{+08}$	$5.20\times10^{+05}$
U-233	$5.79\times10^{+07}$	1.31×10^{-03}	3.80×10^{-05}	$2.40\times10^{+08}$	3	$4.00\times10^{+08}$	$6.10\times10^{+03}$
U-234	$8.90\times10^{+07}$	1.73×10^{-03}	2.43×10^{-05}	$2.30\times10^{+08}$	3	$3.90\times10^{+08}$	$3.10\times10^{+05}$
U-238	$1.63\times10^{+12}$	1.36×10^{-03}	1.65×10^{-05}	2.20×10^{-08}	3	$3.50\times10^{+08}$	$6.30\times10^{+03}$
Y-90	$2.67\times10^{+00}$	1.69×10^{-06}	$0.00\times10^{+00}$	$9.90\times10^{+03}$	1	$5.90\times10^{+04}$	$7.40\times10^{+02}$

for CH-TRU and RH-TRU waste. Radionuclides were ranked as to their potential significance in determining the Transportation Risk Factor using a relative hazard value. The relative hazard value for each radionuclide was calculated by multiplying the anticipated inventory activity fraction of each radionuclide by a dose factor index and a photon energy index and summing the products. The dose factor index for each radionuclide was determined by summing its ingestion and inhalation dose factors (rem/Ci) and dividing by the Pu-239 dose factor sum. Similarly, the photon energy index for each radionuclide was determined by dividing its average photon energy by the maximum photon energy of the radionuclides in the inventory. In this manner, a relative measure of internal and external exposure hazards for each radionuclide could be assessed. Those radionuclides having relative hazard values within four orders of magnitude of the highest value were selected for analysis.

To predict potential radiological impacts from accidents, this analysis uses an accident severity classification scheme and associated probabilities of occurrence derived from NUREG-0170 (NRC, 1977) and the WIPP FSEIS (DOE, 1990b). Accident severity categories define the seriousness of an accident in terms of mechanical and thermal (fire) loads and influence the potential amount of radioactive material released during an accident. Most accidents are unlikely to cause any release, but very severe accidents (much more severe than represented by NRC certification standards for Type B containers) may cause some of the radioactive material to escape. NUREG-0170 defined eight accident severity categories. The first two accident categories were defined to be less serious than the hypothetical accident conditions specified in 10 CFR Part 71 for testing Type B packaging and were retained in this analysis. Thus, use of the TRUPACT-II container and RH-72B cask would be very unlikely to result in any releases to the environment for severity category I or II accidents. NUREG-0170 defined the remaining six categories to postulate increasingly severe, but less likely, accidents resulting in a release of radioactive materials from Type B packages.

A key parameter for analyzing postulated accidents is the estimated release fraction of radioactive material escaping to the environment. Particulates can result from impacts that fracture or suspend the radioactive material or from fires that can entrain impact-generated particulates, cause off-gassing of volatile fission products, or thermally degrade and then entrain particulates from previously intact material. Inhalation is a primary internal exposure pathway for people that results from breathing respirable (<10 microns), aerosolized particulates. As the particulates move downwind, some settle out onto the ground where they can expose people to penetrating radiation. This constitutes the "groundshine" exposure pathway. After settling, some fraction of the particles can also be resuspended into the air due to wind or other surface disturbances. These particulates can then be inhaled by people as were those in the initial plume and constitute the source term for the resuspension dose pathway. Finally, particles in the air can also expose people to penetrating radiation; this constitutes the "cloudshine" exposure pathway. For this analysis, the ingestion pathway (through which particles settle on crops and are subsequently consumed by the public) was not assessed. Reasons for not incorporating the ingestion pathway were that (1) any accident resulting in contamination of crops would result in interdiction of those crops prior to any significant consumption by the public, (2) based on dose conversion factors for the radionuclides of interest, inhalation exposures result in doses typically one to two orders of magnitude greater than those from ingestion for equal uptakes of radioactive material, and (3) the RADTRAN model has not formally adopted radionuclide ingestion parameters (i.e., soil or food transfer factors).

This analysis uses the release fractions developed in Appendix D of the WIPP FSEIS (DOE, 1990b) for postulated accidents involving baseline CH-TRU and RH-TRU waste shipments. The release fraction analysis determined how much radioactive material could be potentially released to the environment in a respirable, airborne form for accident severity categories III through VIII. Larger particle sizes (greater than 10 microns) were not analyzed, as they tend to be eliminated by the body and consequently are not as significant in estimating health effects.

Calculation of respirable release fractions for engineered alternatives No. 1 and No. 77 (supercompacted waste) followed the WIPP FSEIS methodology. The fraction of material released from failed containers was reduced by one third for severity categories III through VII, reflecting greater crush resistance of the drums (less void space) and that there will typically be four supercompacted pucks in each drum. Additionally, the fraction of material aerosolized from impact was reduced by an order of magnitude to reflect reduced aerosolization of the supercompacted waste form by impact forces. Similarly, the fraction of material entrained to the environment was reduced by an order of magnitude to represent the supercompacted waste form. Finally, the fraction of material aerosolized by the postulated thermal event was also reduced by an order of magnitude to account for the reduced surface area of the supercompacted waste form.

Calculation of respirable release fractions for engineered alternative No. 6 (compacted/shredded waste) also followed the WIPP FSEIS methodology. The fraction of material released from failed containers was reduced by one third (assumed same as supercompacted waste) for the lower accident severity categories (III, IV, and V). This accounts for the increased crush resistance of the drums due to compaction but recognizes that it is not as great as with supercompaction. The fraction of material aerosolized by the thermal event was increased by an order of magnitude to reflect the increased surface area of the shredded material. It was assumed that engineered alternative No. 94 waste forms would have similar release fractions because they have essentially the same treated waste matrices, except that clay is added to enhance repository performance.

Calculation of release fractions for engineered alternative No. 10 waste forms required the use of alternative analysis methodologies. The products of plasma processing are vitrified glasses and solid metals and are anticipated to be able to withstand severe temperatures. Respirable impact releases were determined using impact test data for vitrified materials (Pacific Northwest Laboratories, 1975). The amount of material fractured at an impact velocity of 66 feet per second ranged from 0.013 to 0.15 percent. The upper value of this range was used as the amount of material released for accident severity category VIII. RADTRAN default values for an immobile material for the aerosol fraction and the respirable fraction were applied to the estimated material released to quantify the respirable impact release. This value was conservatively applied to accident severity categories III through VIII. Under thermal accident conditions, vitrified materials are anticipated to behave like refractory brick. The primary release mechanism is expected to be the aerosolization of material from contaminated surfaces. Any such releases are anticipated to occur only at the more severe accident categories involving a prolonged fire (category IV through VIII). The Nuclear Fuel Cycle Facility Accident Analysis Handbook (Ayer et al., 1988) recommends a thermal suspension factor of 2.5×10^{-5}/s. This analysis assumed that there is an effective thermal suspension duration of one hour and that 10 percent of the material fractured is available for release under severity category VIII accident conditions. Additionally, a decontamination factor of 5×10^{-2} was used for releases from the package cavity to the environment. This is consistent with values used in Transportation—Accident Scenarios for Commercial Spent Fuel (Wilmot, 1981) and takes credit for mitigation processes reducing radioactive material releases such as particulate settlement, plateout, and filtration effects along the leak path. The resulting respirable thermal release fraction was conservatively applied to accident severity categories IV through VIII. The total respirable release fraction was determined by summing the impact and thermal release components.

Table 3-39 summarizes the resulting radioactive material release fractions for postulated accidents for the baseline and engineered alternatives evaluated in this study. Radiological exposures to internal and external doses of radiation are reported in units of rem (individual dose) or person-rem (collective dose to a group of individuals). The average annual dose of ionizing radiation to a member of the U.S. population is estimated to be 0.36 rem (National Council on Radiation Protection and Measurements, 1987). This includes both natural sources (e.g., radon) and artificial sources (e.g., diagnostic x-rays). Principal adverse effects from human exposure to low-level ionizing radiation are carcinogenicity (ability to cause cancer), mutagenicity (ability to cause inheritable defects), and teratogenicity (ability to cause noninheritable birth defects). For low-level exposures, the most significant risk is that of latent (delayed) cancers. The summation of radiation doses (collective dose) to a group of individuals may be multiplied by a dose-to-risk conversion factor to estimate the number of incremental latent cancer fatalities (LCFs) associated with the postulated exposure. Use of a dose-to-risk conversion factor of 500 LCFs per million person-rem (5.0×10^{-4} LCFs/person-rem) for the general population and of 400 latent cancer fatalities per million person-rem (4.0×10^{-4} LCFs/person-rem) for workers are currently accepted values (NRC, 1991). This difference in dose-to-risk conversion factors for the two population groups is attributable to the presence of children in the general population.

3.5.2.1.3 Hazardous Chemical Exposures

The hazardous chemical analysis is based on the methodology presented in the Transportation Alternatives report (DOE, 1994a). As the scope of the current chapter and above-mentioned report is limited to the analysis of transportation impacts from the gate of the shipment origin site to the gate of the treatment or disposal site, no handling of waste containers is considered. Additionally, the hazardous chemical constituents of the waste are completely contained within the shipment package (i.e., TRUPACT-II or RH-72B cask). Because of the integrity and leak tightness of these Type B packages, it can be concluded that the shipment of hazardous chemical waste constituents presents an insignificant hazard to workers and the public under incident-free transportation conditions.

While it is very unlikely that an accident will breach a Type B package, such an accident is credible and constitutes a potential chemical exposure source to the public. Comparison of resulting airborne chemical concentrations to an accepted level of protection is used as the basis for determining the chemical component of the Transportation Risk Factor. Because predicted airborne chemical concentrations are determined by the waste form (i.e., untreated, supercompacted, vitrified) and associated release mechanisms, the chemical component of the Transportation Risk Factor is affected by the engineered alternative considered and not by the decentralized, regionalized, or centralized configurations to be evaluated. Thus, each engineered alternative considered will have one chemical risk factor, which will be the same for all configurations.

The chemical assessment was performed based on a very severe shipment accident. Maximum impacts were evaluated by assuming a severity VIII category accident and associated releases. The risk factor was evaluated by comparing maximum airborne chemical concentrations for a member of the public with concentrations based on Emergency Response Planning Guideline 2

1 **TABLE 3-39**

TRU WASTE TRUCK SHIPMENT RELEASE FRACTIONS FOR POSTULATED ACCIDENTS[1]

	Accident Severity Category							
Scenario	I	II	III	IV	V	VI	VII	VIII
Baseline[2]								
CH-TRU Waste	$0x10^{-00}$	$0x10^{-00}$	$8x10^{-09}$	$2x10^{-07}$	$8x10^{-05}$	$2x10^{-04}$	$2x10^{-04}$	$2x10^{-04}$
RH-TRU Waste	$0x10^{-00}$	$0x10^{-00}$	$6x10^{-09}$	$2x10^{-07}$	$1x10^{-04}$	$1x10^{-04}$	$2x10^{-04}$	$2x10^{-04}$
CH-TRU Waste Engineered Alternatives[3]								
Alternative No. 1 & 77	$0x10^{-00}$	$0x10^{-00}$	$8x10^{-09}$	$2x10^{-08}$	$2x10^{-06}$	$5x10^{-06}$	$7x10^{-06}$	$2x10^{-05}$
Alternative No. 6	$0x10^{-00}$	$0x10^{-00}$	$1x10^{-08}$	$2x10^{-06}$	$3x10^{-05}$	$2x10^{-04}$	$2x10^{-04}$	$2x10^{-04}$
Alternative No. 10	$0x10^{-00}$	$0x10^{-00}$	$8x10^{-11}$	$7x10^{-08}$	$7x10^{-08}$	$7x10^{-08}$	$7x10^{-08}$	$7x10^{-08}$
Alternative No. 94	$0x10^{-00}$	$0x10^{-00}$	$1x10^{-08}$	$2x10^{-06}$	$3x10^{-05}$	$2x10^{-04}$	$2x10^{-04}$	$2x10^{-04}$

[1]Tabulated release fractions are for the final waste form.
[2]Baseline release fractions based on the WIPP FSEIS (Appendix D, TABLES D.3.21 and D.3.22) (DOE, 1990b).
[3]See Section 3.5.2.1.2 text for basis of engineered alternative release fractions.

(ERPG-2). An ERPG-2 is defined as the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action (AIHA, 1989). This is an appropriate exposure level for the public and is consistent with the recommendations in the DOT 1990 Emergency Response Guidebook (DOT, 1990).

ERPG-2 values are developed based on an anticipated one-hour exposure. To address a postulated two-hour exposure, the ERPG-2 value was halved to provide an adjusted ERPG-2 value. This is a more stringent exposure level for comparing two-hour release concentration values with calculated chemical airborne concentrations. This comparison was accomplished by dividing the maximum calculated receptor concentrations for each chemical by the adjusted ERPG-2 value. Ratios smaller than unity indicate that exposures fall within health-based reference levels. Additionally, the individual chemical ratios were summed and compared to unity. This provides an indication of potential cumulative effects for exposure to multiple chemicals even though it does not take into consideration possible synergistic effects among the chemicals.

Based on the relative shipment capacity of the TRUPACT-II (308.7 cubic feet per drum shipment and 389.1 cubic feet (11.02 cubic meters) per SWB shipment) versus the relative shipment capacity of the RH-72B (31.4 cubic feet [0.89 cubic meters]) and the chemical characterization data presented in the Interim Mixed Waste Inventory Report (DOE, 1993a), it is concluded that hazardous constituent accident analyses for CH-TRU waste baseline shipments are bounding for RH-TRU waste baseline shipments.

An initial screening analysis was performed to identify potential chemicals for analysis under accident conditions. Table C-1 of the WIPP RCRA Part B Permit Application (DOE, 1993b) and the TRUPACT-II List of Chemical Compounds in Each Content Code in TRUCON (DOE, 1994g) were reviewed to identify chemicals found in CH-TRU waste streams for INEL, Hanford Site, RFETS, and Savannah River Site. Waste streams from these sites are currently projected to constitute 82 percent of the CH-TRU waste to be emplaced at the WIPP. Chemicals were retained as candidates for analysis if an airborne concentration limit could be found for the chemical of interest. Concentration limits considered included:

- The EPA list of acutely hazardous substances having levels of concern (LOCs)

- Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) values

- American Industrial Hygiene Association Emergency Response Planning Guideline (ERPG) values

- American Conference of Governmental Industrial Hygienists Threshold Limit Values (TLVs)

Following the initial screening analysis, chemicals were further ranked as to their potential health significance using a relative hazard value. The relative hazard value for each chemical was determined by dividing the hazard value for a given chemical by the maximum hazard value for all the chemicals in the respective table. The hazard value was calculated as the fraction (concentration) of the chemical in the waste matrix divided by the airborne concentration limit of the subject chemical. Thus, the higher a chemical concentration in a waste matrix or the lower its airborne concentration limit, the greater its potential hazard. All substances having a relative hazard value within 1 percent of the maximum relative risk value were retained for final analysis. The 20 chemicals that fell within 1 percent of the maximum hazard value and that were selected for further analysis are presented in Table 3-40.

Chemical concentrations in the waste matrix were estimated using Table C-1 of the WIPP RCRA Part B Permit Application (DOE, 1993b) and the TRUPACT-II list of chemical compounds in each content code in TRUCON (DOE, 1994g). These documents provide concentration values for chemicals in the various waste matrices. Chemicals were typically reported as either dominant (>10 weight percent), minor (1-10 weight percent), trace (<1 weight percent), trace 1 (< 0.1 weight percent), trace 2 (low parts per million [ppm] range), or trace 3 (<1 ppm by weight). The following concentration values were assigned for each category (fraction by weight):

Dominant	(D) –	0.3
Minor	(M) –	0.10
Trace	(T) –	0.01
Trace 1	(T1) –	0.001
Trace 2	(T2) –	0.0001
Trace 3	(T3) –	no chemicals passing the initial screening were in this category.

The analysis used the highest reported nominal concentration for a given chemical, with the exception of cadmium, due to the variability of its concentration in the waste forms considered (maximum reported value is "D," value utilized is "M").

Airborne chemical concentrations for the maximally exposed member of the public were determined using the Gaussian Dispersion Plume equation of Pasquill as modified by Gifford (1961) for ground-level concentrations at the centerline of the plume:

$$\chi = [Q/(\pi \sigma_y \sigma_z \mu)] \exp [-.5 (H/\sigma_z)^2], \quad 3.8$$

where

χ = contaminant airborne concentration at x meters downwind, mg/m^3
Q = contaminant release rate, mg/s
μ = mean wind speed, m/s
σ_y = horizontal dispersion coefficient, m
σ_z = vertical dispersion coefficient, m
H = effective release height, m.

The above equation does not incorporate plume depletion effects from particulate settlement (by gravitational or chemical effects) and thus will overstate air concentrations and resulting inhalation exposures. Additionally, each accident was postulated to occur during a period having very stable atmospheric meteorological conditions (Pasquill Stability Class F, wind speed of 1 m/s). Use of these unfavorable meteorological conditions introduces additional conservatism into the analysis.

The following short-term dispersion coefficients (Slade, 1968) were incorporated in the Gaussian Plume Dispersion equation:

1 **TABLE 3-40**

SELECTION OF CHEMICAL CONSTITUENTS IN CH-TRU WASTE FOR FURTHER ANALYSIS

Chemical Name	CAS Number	Quantity Code[1]	Fraction in Waste Matrix[2]	ERPG-2 (ppm)	ERPG-2 Source[3]	Hazard Value	Relative Hazard Value
Beryllium	7740-41-7	T	0.01	0.01	c	$1.00\times10^{+00}$	2.33×10^{-01}
Bromine	7726-95-6	T	0.01	1.00	c	1.00×10^{-02}	3.33×10^{-02}
Cadmium (fume)	7440-43-9	D	0.3	0.07	b	$4.29\times10^{+00}$	9.99×10^{-01}
Carbon tetrachloride	56-23-5	D	0.3	25.00	b	1.20×10^{-02}	4.00×10^{-02}
Cellulose	9004-34-6	D	0.3	25.00	a	1.2×10^{-02}	4.00×10^{-02}
Chloroform	67-66-3	D	0.3	100.00	d	3.00×10^{-03}	1.00×10^{-02}
Chlorosulfonic acid	7790-94-5	T	0.01	2.10	c	4.76×10^{-03}	1.59×10^{-02}
Chromium VI compounds,as Cr		T	0.01	0.10	a	1.00×10^{-01}	2.33×10^{-02}
Copper (fume)	7440-50-8	M	0.1	0.40	a	2.50×10^{-01}	5.83×10^{-02}
Hydrazine	302-01-2	T	0.01	0.80	c	1.25×10^{-02}	4.17×10^{-02}
Lead	7439-92-1	D	0.3	0.09	a	$3.33\times10^{+00}$	7.77×10^{-01}
Mercury (inorganic)	7439-97-6	T	0.01	0.01	b	$1.00\times10^{+00}$	2.33×10^{-01}
Oxalic acid	144-62-7	T	0.01	1.50	a	6.67×10^{-03}	2.22×10^{-02}
Platinum	7440-06-4	M	0.1	0.50	a	2.00×10^{-01}	4.66×10^{-02}
Phosphoric acid	7664-38-2	T	0.01	1.50	a	6.67×10^{-03}	2.22×10^{-02}
Silver	7440-22-4	T	0.01	0.10	a	1.00×10^{-01}	2.33×10^{-02}
Sodium hydroxide	1310-73-2	T	0.01	1.20	b	8.33×10^{-03}	2.78×10^{-02}
Tributyl phosphate	126-73-8	D	0.3	1.00	a	3.00×10^{-01}	$1.00\times10^{+00}$
Tungsten (sol. Compounds as W)	7440-33-7	M	0.1	0.50	a	2.00×10^{-01}	4.66×10^{-02}
Uranium	7440-61-1	T	0.01	0.10	a	1.00×10^{-01}	2.33×10^{-02}

[1]D = Dominant; M = Minor; T = Trace
[2]Chemical concentrations in the waste matrix are conservatively estimated based on the assigned quantity codes for use in the risk analysis and are not representative of average TRU waste characteristics.
[3]a. TLV-TWA X5; b. PEL-C; c. ERPG-2; d. LOC

$\sigma_y = 0.02\ (x)^{.89}$
$\sigma_z = 0.05\ (x)^{.61}$
x = downwind distance, m

The effective height (H) of the accident plume was estimated as approximately 69 feet (21 meters). This takes into consideration the buoyancy rise associated with the thermal effects from the accident. Thermal effects (e.g., hydrocarbon fuel fire) are expected to play a major role in any loss-of-containment scenario. The buoyancy rise was determined using a heat emission of $8.3 \times 10^{+4}$ watts/m^2, based on hydrocarbon fuel fire tests (Gregory et al., 1987).

The resulting maximum receptor concentration for a member of the public was calculated as:

Receptor concentration (maximum individual) = χ/Q (maximum individual) × Release Rate (mg/s) (3.9)

where:	χ/Q (maximum individual)	=	1.13×10^{-04} s/m^3
	Release Rate	=	Release Quantity (mg)/7200 (s) (assumes a two-hour release)
	Release Quantity	=	Release fraction x fraction of waste chemical is present x chemical fraction in waste x weight of waste/shipment.

Thus, receptor chemical concentrations for postulated accidents will vary by engineered alternative as determined by how the final waste form affects the release fraction, the chemical fraction in the waste, and the density of the waste matrix.

Quantities of hazardous constituents released during the maximum accident were determined using the following bases:

- A severity category VIII accident occurs, resulting in a breach of all three TRUPACT-II packages, and involves both impact and thermal release mechanisms.

- The CH-TRU waste matrix form and density vary by engineered alternative.

- Chemicals released as respirable particulate matter will have a release fraction as determined for the radiological analysis.

- Chemicals released as vapors will have a release fraction dependent on their vapor pressure at the elevated temperature conditions of the TRUPACT-II under accident conditions.

- The fraction of a TRU waste shipment containing the hazardous chemicals of interest was determined on a systemwide-average basis.

- The Interim Mixed Waste Inventory Report (DOE, 1993a) (Chapter 4.0, Table 4-1, and site waste profile sheets) was used to estimate the fraction of CH-TRU waste volume (or shipment) for which each hazardous constituent of interest is present.

3.5.2.1.4 Nonradiological/Non-chemical Risks

The methodology presented in the WIPP FSEIS (DOE, 1990b) was used to estimate the range of non-radiological and non-chemical risks, which involve traumatic injuries and fatalities that are independent of the characteristics of the cargo (Table 3-41).

The HIGHWAY model (Johnson et al., 1993) was used to determine truck travel mileages and travel distance in rural, suburban, and urban population zones. The model incorporates updated 1990 census data.

Estimates of per-shipment risk include accident-related injuries and fatalities of a single TRU waste shipment (round trip) to the WIPP. Cumulative risk estimates were determined by multiplying per-shipment risks by the total number of shipments.

3.5.3 Assumptions and Data Used

3.5.3.1 Number of Waste Shipments

Number of waste shipments is dependent on a site-by-site volume. The analysis in this chapter assumes that a total volume of 6.2 million cubic feet (0.17 million cubic meters) of TRU waste will be emplaced at WIPP. This total includes 5.95 million cubic feet (0.16 million cubic meters) of CH-TRU waste and 250,000 cubic feet (7078.3 cubic meters) of RH-TRU waste. Tables R-20 and R-21 in Appendix R ("Waste Volumes and Inventories") present the CH-TRU and RH-TRU waste volumes for each site. The volumes have been scaled up to reach repository emplacement limits.

The following assumptions were used to estimate the site-by-site shipment volume for TRU waste (Wagner, March 1995):

CH-TRU waste
- 7.35 cubic feet (0.208 cubic meters) per drum
- 64.85 cubic feet (1.836 cubic meters) per SWB
- 14 drums per TRUPACT-II
- 2 SWBs per TRUPACT-II
- 3 TRUPACT-IIs per shipment
- 308.7 cubic feet (8.74 cubic meters) per drum shipment
- 389.1 cubic feet (11.02 cubic meters) per SWB shipment

RH-TRU waste
- 31.4 cubic feet (0.89 cubic meters) per RH-72B cask
- one RH-72B cask per shipment
- 31.4 cubic feet (0.89 cubic meters) per shipment

TABLE 3-41

NONRADIOLOGICAL AND NONCHEMICAL UNIT RISK FACTORS

Mode	Zone	Injuries/Mile	Fatalities/Mile
Truck	Rural	1.33×10^{-06}	1.09×10^{-07}
	Suburban	6.32×10^{-07}	2.69×10^{-08}
	Urban	6.16×10^{-07}	1.54×10^{-08}

3.5.3.2 Waste Characteristics

Baseline waste characteristics were primarily established using two information resources: (1) the Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report (DOE, 1995e) and (2) the Comparative Study of Waste Isolation Pilot Plant (WIPP) Transportation Alternatives (DOE, 1994a), which was prepared to meet requirements of the LWA. In subsequent discussions, these reports are referred to as the BIR and the Transportation Alternatives report, respectively. The BIR was used to establish waste forms and densities and their corresponding radionuclide content and distribution. Average sitewide information was incorporated into the analysis. The Transportation Alternatives report was used to quantify hazardous chemical concentrations in the TRU waste matrices. The information presented in the Transportation Alternatives report was derived from (1) the U.S. Department of Energy Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capabilities and Technologies (DOE, 1993a); (2) Table C-1 of the Waste Isolation Pilot Plant Resource Conservation and Recovery Act (RCRA) Part B Permit Application (DOE, 1993b); and (3) the Waste Isolation Pilot Plant, TRUPACT-II List of Chemical Compounds in Each Content Code in TRUCON (DOE, 1994g).

Final waste forms and associated characteristics for the engineered alternatives were determined using the program information presented in Section 2.3 and supporting appendices. As with the baseline analysis, waste form characteristics were evaluated on an average sitewide basis.

As previously discussed in Section 3.5.2.1.2, a screening analysis was performed to identify the radionuclides of primary concern for the transportation risk assessment. The disposal radionuclide inventory presented in Chapter 4.0 of the BIR identifies approximately 139 radionuclides in the CH-TRU and RH-TRU waste. These radionuclides result from the varied waste operations throughout the DOE complex and the ingrowth of daughter products during the radioactive decay process. Based on the screening analysis, a manageable and representative evaluation was possible with the inclusion of 36 of the radionuclides.

3.5.4 Results of the Analysis of the Transportation Risk Factors

3.5.4.1 Radiological Exposures

Appendix L, "Transportation Risk," provides tables of data that are the outcome of the analysis of transportation risk factors. The following subsections discuss key aspects of these data as they apply to risks of radiological and hazardous chemical exposures and to nonradiological/ nonchemical risks.

3.5.4.1.1 Baseline

The detailed results of the radiological Transportation Risk Factor analysis for baseline CH-TRU and RH-TRU waste shipments are presented in Tables L-1 through L-4 in Appendix L. Risk factor values are provided on a per-shipment basis and for cumulative/lifetime shipments for each applicable route segment. As discussed in the methodology section, incident-free risk factor doses are determined for the truck crew, the public, and the maximum member of the public residing or working along the transportation route corridor. The accident risk dose factor provides a probabilistic measure of doses to the public resulting from a spectrum of postulated accidents ranging from minor incidents (no radiological material released) to very severe accidents (incident exceeds Type B packaging test conditions).

Major CH-TRU sites (Hanford, INEL, LANL, RFETS, and SRS) involve almost 98 percent of all CH-TRU waste shipments and account for a comparable percentage of total radiological doses (incident-free and accident risks) to the public. Similarly, major RH-TRU sites (Hanford and ORNL) comprise 90 percent of all RH-TRU waste shipments and account for almost 99 percent of incident-free public doses and 96 percent of accident risk doses to the public for RH-TRU waste shipments. It is noted that while the number of RH-TRU waste shipments equals approximately 45 percent of the number of CH-TRU waste shipments, total RH-TRU incident-free public doses are projected to equal almost 83 percent of the total CH-TRU value. Also, calculated maximum individual doses are anticipated to be greater for RH-TRU waste shipments. This results from the higher TI values for RH-TRU waste shipments. The hypothetical maximum individual exposed to every TRU waste shipment is predicted to receive a cumulative dose of 1.7×10^{-2} rem over the lifetime of WIPP operations.

It is observed that Hanford RH-TRU waste constitutes the large majority of RH-TRU shipment radiological risks. Additionally, this site was estimated to have a shipment TI value (69 mrem/hr; Table 3-37) exceeding regulatory limits for exclusive-use vehicles. RADTRAN dose calculations were performed using regulatory limit values; however, the analysis suggests that proper load management, additional waste shielding, or reduced payload capacity options may need to be addressed.

3.5.4.1.2 Engineered Alternatives Nos. 1 and 77

As discussed in Section 3.5.2, engineered alternatives No. 1 and No. 77 have similar final waste forms and, as such, have similar Transportation Risk Factors. Both incident-free risk factor doses and accident risk doses were determined. Predicted values are summarized in Appendix L Tables L-5 through L-10 for the decentralized, regionalized, and centralized configurations. Per-shipment and cumulative WIPP lifetime risk factors are tabulated for each configuration.

As with the baseline analysis, major CH-TRU sites comprise the large majority of waste shipments and account for a comparable percentage of total radiological risks. Population risks (i.e., crew, public) are greatest for the centralized configuration and lowest for the decentralized configuration; however, all configuration values are within 16 percent of each other. Maximum hypothetical individual doses are highest for the regionalized configuration and lowest for the decentralized configuration. This is largely due to the increased number of shipments associated with the regionalized configuration (approximately 355 more shipments than the decentralized configuration). With this difference, maximum hypothetical individual doses vary by 38 percent.

Comparing baseline with engineered alternative No. 1 and No. 77 radiological risk factors, it can be concluded that:

- There are no significant differences in the extent of radiological risks.

- The decentralized and regionalized configurations for the engineered alternatives result in nominal reductions in population radiological risks.

- The centralized configuration for the engineered alternatives has essentially the same level of risk as the baseline, as expected, because shipment waste forms and movements are comparable.

3.5.4.1.3 Engineered Alternative No. 6

Predicted radiological Transportation Risk Factors for engineered alternative No. 6 are presented in Appendix L Tables L-11 through L-14 for the decentralized and regionalized configurations. Risk factors are provided on a per-shipment and cumulative WIPP lifetime basis for each configuration. As with the foregoing analyses, both incident-free doses and accident risk doses are tabulated. Radiological risk factors for the centralized configuration are identical to those presented in Table L-9 (per shipment) and Table L-10 (cumulative WIPP lifetime). In fact, all engineered alternatives will have the same radiological risk factors for the centralized configuration because all have identical shipment waste forms and movements.

As with the other engineered alternatives, major CH-TRU waste shipment sites account for the large majority of radiological risks. All three configurations for the engineered alternative result in comparable levels of risk. Incident-free population doses are projected to be the highest for the centralized configuration and comparable for the decentralized and regionalized configurations. Maximum hypothetical individual doses are highest for the regionalized configuration and lowest for the decentralized configuration. This will tend to be true for all engineered alternatives due to the previously noted increase in the number of shipments associated with the regionalized configuration. Accident risk doses for the centralized configuration are predicted to be nominally higher (approximately 5 percent) than the decentralized and regionalized configurations.

Comparison of engineered alternative No. 6 radiological risk factors with those for the baseline results in conclusions similar to those derived for alternative No. 1 and No. 77; namely, there are no significant differences in the extent of radiological risks.

3.5.4.1.4 Engineered Alternative No. 10

The results of the radiological Transportation Risk Factor analysis for engineered alternative No. 10 are summarized in Appendix L Tables L-15 through L-18. Risk factor values for the decentralized and regionalized configurations are tabulated. As discussed in Section 3.5.4.1.3, all engineered alternatives will have identical radiological risk factors for the centralized configuration as listed in Tables L-9 and L-10.

All three configurations for the engineered alternative result in comparable incident-free population doses to the crew members and the public. All values are within approximately 7 percent of each other. As previously observed, the regionalized configuration results in the highest dose for the hypothetical maximum individual and is approximately 32 percent higher than the decentralized value (lowest maximum individual dose). The accident risk doses for the decentralized and regionalized configurations are over an order of magnitude lower than the centralized configuration value. These reduced accident risks result from the reduced release fraction estimates for the engineered alternative vitrified waste form.

There are no significant differences between engineered alternative No. 10 and the baseline for incident-free doses. However, the subject alternative does provide significantly reduced accident risk doses (by over an order of magnitude) due to the reduced released fractions associated with the immobilized waste form for postulated accidents.

3.5.4.1.5 Engineered Alternative No. 94

Appendix L Tables L-19 through L-22 present calculated radiological risk factors for engineered alternative No. 94. Risk factors are provided on a per-shipment and cumulative WIPP lifetime basis for the decentralized and regionalized configurations. Centralized configuration risk factors are summarized in Tables L-9 and L-10.

Radiological Transportation Risk Factors are comparable for all three configurations. The treated waste form for this alternative is similar to that for engineered alternative No. 6, with the exception that clay is added to the shredded waste matrix. This has the effect of reducing the average radionuclide density and increasing the mass density of the treated waste matrix. Both effects tend to reduce the shipment TI value for the treated waste form. Consequently, incident-free doses for engineered alternative No. 94 are approximately 32 percent less than those for engineered alternative No. 6.

Radiological risk factors for the three configurations are comparable with those for the baseline, although it can be concluded that the decentralized and regionalized configurations provide risk reductions ranging from 28 percent to 46 percent, depending on the specific risk parameter considered (i.e., crew, public, or maximum individual doses or accident risks).

3.5.4.2 Hazardous Chemical Exposures

3.5.4.2.1 Baseline

The results of the baseline chemical exposure analysis are presented in Table L-23 of Appendix L. As described in Section 3.5.2.1.3, the analysis postulates that a very severe accident occurs and compares the predicted receptor (maximum member of the public) airborne concentrations with adjusted ERPG-2 values. This was done by dividing the calculated receptor concentration by the adjusted ERPG-2 value for each hazardous chemical. Ratios smaller than one indicate that exposures fall within health-based reference levels.

Table L-23 of Appendix L shows that all individual chemical concentration/ERPG-2 ratios for the postulated maximum exposed individual are acceptable. The combined chemical exposure ratio exceeds a value of one (1.2). This suggests that irreversible or other serious health effects cannot be excluded from occurring; however, the conservatisms incorporated into the analysis (as discussed in Section 3.5.2.2) make it highly likely that the occurrence of any such postulated event would fall within health-based reference levels and would be acceptable.

Based on the relative shipment capacity of the TRUPACT-II and the RH-72B cask and on current chemical characterization data, it can be concluded that hazardous chemical accident analyses for CH-TRU waste shipments bound RH-TRU waste shipments.

3.5.4.2.2 Engineered Alternatives

Chemical airborne releases for engineered alternatives No. 1, 6, 10, 77, and 94 are summarized in Table L-24 of Appendix L for a postulated very severe accident. The release form, release fraction, and receptor concentration/ERPG-2 ratios are tabulated for each engineered alternative.

Engineered alternatives No. 1 and 77 have the highest combined chemical exposure hazard, followed by engineered alternative No. 6. Engineered alternatives No. 10 and 94 have combined chemical exposure ratios that fall within health-based reference levels and for which it can be concluded that no irreversible or other serious health effects are expected to occur. For all engineered alternatives, individual chemical exposure ratios for engineered alternatives No. 1, 6, and 77 exceed one, indicating that irreversible health effects cannot be excluded from occurring. As noted in Section 3.5.3.2.1, the analysis incorporates several conservatisms. It can be concluded that the levels of exposure would not result in any fatalities.

3.5.4.3 Non-radiological/Non-chemical Risks

The non-radiological and non-chemical impacts of transporting TRU waste to the WIPP are the same as those resulting from transporting non-nuclear and non-hazardous materials. The risks involve traumatic injuries and fatalities from transportation accidents. Non-radiological and non-chemical impacts are independent of the characteristics of the cargo and therefore totally unrelated to radiological and hazardous chemical risks resulting from projected accidents. The non-radiological/non-chemical risks are also therefore independent of impacts from waste processing engineered alternatives.

Calculated per-shipment non-radiological and non-chemical risks for CH-TRU and RH-TRU shipments to the WIPP are summarized in Appendix L Table L-25. These risks include the impact of the return trip by truck from the WIPP to the generator or storage facility.

Total cumulative non-radiological and non-chemical CH-TRU and RH-TRU transportation risks are summarized in Appendix L Tables L-26 through L-29 for the entire life of the disposal phase.

3.5.4.4 Uncertainties

The transportation risks estimated in this chapter are affected by a number of uncertainties. For example:

- Waste Volume vs. Waste Mass—Waste volume limited shipments were analyzed to provide an upper bound for the transportation risks. The risks associated with waste mass limited shipments would fall below this upper bound.

- Waste volumes and locations—The risks will either increase or decrease depending on the volume of waste shipped and the distance to WIPP.

- Waste form—The risks in an accident will decrease if the waste is solidified, incinerated, vitrified, etc., because less material would be released. The non-radiological/non-chemical risks will increase if more shipments occur.

- Waste mass—The TRUPACT-IIs and RH-72B casks are weight limited. The waste mass could be such that many shipments could consist of just a few drums, thus increasing the number of shipments.

- TRU waste from environmental restoration activities—To date, the TRU waste volumes for environmental restoration activities have not been factored into WIPP operations.

- Mode of shipment—The analysis presented here is based on all shipments being made by truck. All previous transportation risk assessments for WIPP have analyzed rail shipments as well.

3.5.4.5 Summary of Results

As defined in Section 3.5.1, the Transportation Risk Factor is comprised of three risk components: radiological, chemical, and non-radiological/non-chemical. The radiological risk component is expressed in both doses (person-rem for collective exposures or rem for individual exposures) and health effects (incremental LCFs). These risks result from both incident-free transportation activities and postulated accidents. The chemical risk component provides a measure of the level of hazard for the maximally exposed member of the public for a postulated very severe accident. It is expressed as a unitless number and is calculated as the sum of each airborne chemical concentration divided by its respective ERPG-2 value. Chemical risk component values below 1.0 suggest that nearly all individuals could be exposed without experiencing or developing irreversible or serious health effects which could impair an individual's ability to take protective action. The non-radiological/non-chemical risk component results from non-cargo-related accident impacts and is expressed as traumatic injuries and fatalities.

A summary of the results of the transportation risk analysis is presented in Tables 3-42, 3-43, and 3-44. Table 3-42 summarizes the Transportation Risk Factor for baseline CH-TRU and RH-TRU waste shipments and for CH-TRU waste shipments for the centralized configuration. Tables 3-43 and 3-44 summarize the Transportation Risk Factor for CH-TRU waste shipments for the decentralized and regionalized configurations, respectively. As previously discussed, only five engineered alternatives affect the Transportation Risk Factor (Nos. 1, 6, 10, 77, and 94). Of these, two (Nos. 1 and 77) have the same risk factor values. The remaining engineered alternatives have the same Transportation Risk Factor as the baseline. To quantify the total Transportation Risk Factor for all TRU waste shipments, the baseline RH-TRU waste Transportation Risk Factor must be added to the risk factor for the CH-TRU engineered alternative of interest.

The chemical risk component is not affected by transportation movements and thus varies by engineered alternative but not by transportation configuration. The non-radiological/non-chemical risk component is affected by transportation movements but not by the nature of the waste cargo, and thus varies by transportation configuration but not by engineered alternative. The radiological risk component is affected by both transportation movements and the nature of the cargo and thus varies by both the engineered alternative and the transportation configuration evaluated.

1 **TABLE 3-42**

SUMMARY OF CUMULATIVE/LIFETIME TRANSPORTATION RISK FACTOR BASELINE AND CENTRALIZED CONFIGURATION

	Baseline		Centralized Configuration
	CH-TRU Waste	RH-TRU Waste	All Engineered Alternatives for CH-TRU Waste
Radiological Risk Component			
Crew[1] - person-rem	$6.69\text{x}10^{+02}$	$6.38\text{x}10^{+02}$	$6.69\text{x}10^{+02}$
(LCFs)	($2.68\text{x}10^{-01}$)	($2.55\text{x}10^{-01}$)	($2.68\text{x}10^{-01}$)
Public[1] - person-rem	$4.00\text{x}10^{+03}$	$3.32\text{x}10^{+03}$	$4.00\text{x}10^{+03}$
(LCFs)	($2.00\text{x}10^{+00}$)	($1.66\text{x}10^{+00}$)	($2.00\text{x}10^{+00}$)
Max Individual[1,2,3] - rem	$4.99\text{x}10^{-03}$	$1.20\text{x}10^{-02}$	$4.99\text{x}10^{-03}$
(LCFs)	($2.50\text{x}10^{-06}$)	($6.00\text{x}10^{-06}$)	($2.50\text{x}10^{-06}$)
Accident Risk - person-rem	$8.01\text{x}10^{+01}$	$6.52\text{x}10^{-01}$	$8.01\text{x}10^{+01}$
(LCFs)	($4.01\text{x}10^{-02}$)	($3.26\text{x}10^{-04}$)	($4.01\text{x}10^{-02}$)
Chemical Risk Component			
Max Individual[4] - Total Airborne Concentration/ Adj'd ERPG-2	$1.2\text{x}10^{+00}$	$1.2\text{x}10^{+00}$[5]	Varies by alternative; same as shown on Table 3-42 or 3-43
Non-radiological/Non-chemical Risk Component			
Injuries	$6.61\text{x}10^{+01}$	$3.35\text{x}10^{+01}$	$7.06\text{x}10^{+01}$
Fatalities	$4.87\text{x}10^{+00}$	$2.63\text{x}10^{+00}$	$4.71\text{x}10^{+00}$

[1]Results from incident-free transportation activities.
[2]RADTRAN calculated maximum individual who is exposed to every shipment.
[3]LCF for the maximum individual estimated using the collective dose risk factor for a population exposure.
[4]Assumes a severity category VIII accident occurs.
[5]Bounding CH-TRU waste value used.

1 **TABLE 3-43**

SUMMARY OF CUMULATIVE/LIFETIME CH-TRU WASTE TRANSPORTATION RISK FACTOR DECENTRALIZED CONFIGURATION

	Engineered Alternative			
	No. 1 & 77	No. 6	No. 10	No. 94
Radiological Risk Component				
Crew[1] - person-rem	$5.81x10^{+02}$	$5.47x10^{+02}$	$7.16x10^{+02}$	$4.25x10^{+02}$
(LCFs)	($2.32x10^{-01}$)	($2.19x10^{-01}$)	($2.86x10^{-01}$)	($1.70x10^{-01}$)
Public[1] - person-rem	$3.47x10^{+03}$	$3.27x10^{+03}$	$4.27x10^{+03}$	$2.55x10^{+03}$
(LCFs)	($1.74x10^{+00}$)	($1.64x10^{+00}$)	($2.14x10^{+00}$)	($1.28x10^{+00}$)
Max Individual[1,2,3] - rem	$3.80x10^{-03}$	$3.81x10^{-03}$	$4.61x10^{-03}$	$2.68x10^{-03}$
(LCFs)	($1.90x10^{-06}$)	($1.91x10^{-06}$)	($2.31x10^{-06}$)	($1.35x10^{-06}$)
Accident Risk - person-rem	$5.92x10^{+00}$	$7.59x10^{+01}$	$1.21x10^{+00}$	$5.76x10^{+01}$
(LCFs)	($2.96x10^{-03}$)	($3.80x10^{-02}$)	($6.05x10^{-04}$)	($2.88x10^{-02}$)
Chemical Risk Component				
Max Individual[4] - Total Airborne Concentration/ Adj'd ERPG-2	$1.80x10^{+00}$	$1.20x10^{+00}$	$2.10x10^{-05}$	$8.10x10^{-01}$
Non-radiological/Non-chemical Risk Component				
Injuries	$6.61x10^{+01}$	$6.61x10^{+01}$	$6.61x10^{+01}$	$6.61x10^{+01}$
Fatalities	$4.87x10^{+00}$	$4.87x10^{+00}$	$4.87x10^{+00}$	$4.87x10^{+00}$

[1]Results from incident-free transportation activities.
[2]RADTRAN model calculated maximum individual who is exposed to every shipment.
[3]LCF for the maximum individual estimated using the collective dose risk factor for a population exposure.
[4]Assumes a severity category VIII accident occurs.

1 **TABLE 3-44**

SUMMARY OF CUMULATIVE/LIFETIME CH-TRU WASTE TRANSPORTATION RISK FACTOR REGIONALIZED CONFIGURATION

	Engineered Alternative			
	No. 1 & 77	No. 6	No. 10	No. 94
Radiological Risk Component				
Crew[1] - person-rem	$5.87\times10^{+02}$	$5.53\times10^{+02}$	$7.22\times10^{+02}$	$4.31\times10^{+02}$
(LCFs)	(2.35×10^{-01})	(2.21×10^{-01})	(2.88×10^{-01})	(1.72×10^{-01})
Public[1] - person-rem	$3.50\times10^{+03}$	$3.28\times10^{+03}$	$4.30\times10^{+03}$	$2.58\times10^{+03}$
(LCFs)	($1.75\times10^{+00}$)	($1.64\times10^{+00}$)	($2.16\times10^{+00}$)	($1.29\times10^{+00}$)
Max Individual[1,2,3] - rem	5.30×10^{-03}	5.32×10^{-03}	6.11×10^{-03}	4.19×10^{-03}
(LCFs)	(2.65×10^{-06})	(2.66×10^{-06})	(3.06×10^{-06})	(2.10×10^{-06})
Accident Risk - person-rem	$6.71\times10^{+00}$	$7.65\times10^{+01}$	$1.96\times10^{+00}$	$5.86\times10^{+01}$
(LCFs)	*(3.36×10^{-03})*	*(3.83×10^{-02})*	*(9.80×10^{-04})*	*(2.93×10^{-02})*
Chemical Risk Component				
Max Individual[4] - Total Airborne Concentration/ Adj'd ERPG-2	$1.80\times10^{+00}$	$1.20\times10^{+00}$	2.10×10^{-05}	8.10×10^{-01}
Non-radiological/Non-chemical Risk Component				
Injuries	$5.98\times10^{+01}$	$5.98\times10^{+01}$	$5.98\times10^{+01}$	$5.98\times10^{+01}$
Fatalities	$4.76\times10^{+00}$	$4.76\times10^{+00}$	$4.76\times10^{+00}$	$4.76\times10^{+00}$

[1]Results from incident-free transportation activities.
[2]RADTRAN calculated maximum individual who is exposed to every shipment.
[3]LCF for the maximum individual estimated using the collective dose risk factor for a population exposure.
[4]Assumes a severity category VIII accident occurs.

3.6 IMPACT ON PUBLIC CONFIDENCE IN THE PERFORMANCE OF THE DISPOSAL SYSTEM

3.6.1 Definition of Factor 6

Identifying and understanding public concern about real or perceived risks associated with WIPP in its postclosure state provide important information that can assist the DOE in:

- Planning and executing sound engineered alternatives to eliminate potential postclosure risks and address public concerns.

- Providing credible scientific bases and data to assist the public in understanding risk probabilities as related to posed concerns and comments.

- Actively involving the general public in the WIPP development process to ensure a two-way flow of information that fosters openness and credibility.

This study was conducted in two phases to identify both historic and current public concerns about WIPP's postclosure performance. During Phase 1, some significant existing public commentary was examined to identify concerns about postclosure WIPP. These comments and concerns were further analyzed to determine the relative frequency of the concerns, the persistence of concerns over time, and the geographic source of concerns. Data sources included:

- The WIPP FSEIS (DOE, 1990b).

- Response to Comments for Amendments to 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (EPA, 1993)

- Public Hearings on EPA's Proposed Rule 40 CFR Part 194, Criteria for the Certification and Determination of the WIPP's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes, March 21-24, 1995 (EPA, 1995).

During Phase 2, comments were collected during a series of focus group discussions and interviews held in Carlsbad, Albuquerque, and Santa Fe, New Mexico, in which participants were invited to share their concerns about postclosure WIPP. These cities were selected as sites for the meetings because they were communities which have major population centers with residents that have shown interest in WIPP. Focus group discussions were held in Carlsbad on June 26, 1995; Albuquerque, on June 27, 1995; and Santa Fe on June 28, 1995. Additionally, interviews were held with three individuals who were invited but unable to participate in the focus group discussions. The Carlsbad interviews were held on July 6 and July 10, 1995, and the Santa Fe interview was conducted on June 28, 1995.

The combined findings from Phase 1 and Phase 2 analyses serve as considerations for selecting EAs that would address expressed public concern.

3.6.2 Methodology Used to Evaluate the Public Confidence Factor (Factor 6)

The data sources used as a source of public comments for the Phase I portion of this study were selected for several reasons:

- There are well-organized and published records of extensive public comments in the WIPP FSEIS. The FSEIS provided a wealth of commentary for developing a taxonomy of public postclosure concerns.

- The series of public hearings held in Carlsbad, Albuquerque, and Santa Fe during the period March 22-24, 1995, regarding EPA's Proposed Rule 40 CFR Part 194, *provided an excellent opportunity for collection of contemporary public concerns* about postclosure WIPP.

- The six years of elapsed time between the comments documented in the WIPP SEIS and those collected in March 1995 provide an opportunity to examine public concerns over a period of time. A comparison between the two, allowed analysts to identify possible shifts in public concerns since the oral and written comments were made as contained in the FSEIS.

The focus group discussions held in Carlsbad, Albuquerque, and Santa Fe, New Mexico were composed of community and business leaders, public opinion leaders, and advocacy group leaders. A proposed list of stakeholders to be asked to participate in the focus group discussions was developed for each location and was presented to Westinghouse Waste Isolation Division (WID) and the DOE-CAO for review and approval. This list was developed (1) by reviewing the EA stakeholder list, (2) through discussions with WIPP personnel, (3) from team knowledge of local communities and stakeholders, and (4) by reviewing the lists of attendees at the EPA 40 CFR Part 194 public hearings. Criteria for selection of focus group discussion participants included the following:

- Demonstrated long-term and abiding interest in the WIPP

- Business and community leaders who represent more than just a singular point of view

- Interest in the WIPP demonstrated by providing oral and/or written comments at public hearings on WIPP.

These selection criteria were developed to ensure that a diverse group, representative of New Mexico, was selected and that focus group participants had some knowledge about WIPP before the meeting. The final list of proposed participants for each location was presented to WID and DOE-CAO for review and approval. No participant attended more than one focus group discussion.

3.6.2.1 Data Collection and Formatting

Development of a Comment Taxonomy for Phase 1

The WIPP FSEIS represents the most comprehensive collection of formally organized public commentary about the WIPP Project. Published in 1990, the FSEIS records 1591 oral and 4948 written comments that express a wide range of public concerns. For example, there are comments related to potential economic and social impacts, comments on the geologic characteristics of the underground site, and comments on the possible risks to endangered species. In short, the comments are wide-ranging in content and depth.

For purposes of this study, a comment classification scheme was developed by identifying within the FSEIS those comments relating to issues about postclosure WIPP. This classification system was refined into the taxonomy of public concerns shown on Figure 3-16, WIPP Postclosure Concerns Phase 1 Taxonomy, which presents the relative frequency of public comments by category and are described below.

Phase 1 Comment Taxonomy

- 1.0 Conditions—Conditions seen as potential causes for undesirable outcomes. This category of comment is broken down further into three subcategories.
  - 1.1 Waste Characteristics—Attributes (e.g., origin, volume, quantity) of the waste proposed for disposal at the WIPP facility.
    - 1.1.1 Characterization/identification—Radioactivity level of waste (e.g., curie level), commercial waste, hazardous wastes, hazardous chemical constituents, etc.
    - 1.1.2 In-storage reactions—Gas generation, heat generation.
    - 1.1.3 Treatment—Vitrification, cementation, etc.
  - 1.2 Waste Repository Technology Applied—Aspects, appropriateness, and nature of technologies to be used at the WIPP.
    - 1.2.1 Siting—Geological, hydrological aspects of the WIPP site itself.
    - 1.2.2 Design—Plugs and seals, backfill, etc.
  - 1.3 Disposal Period Events—Outcomes regardless of cause that could introduce adverse risk to the environment.
    - 1.3.1 Human-caused intrusion—Mining, drilling, sabotage, terrorism
    - 1.3.2 Intrusion due to natural causes—Seismic, climatic changes (e.g., substantially increased precipitation), tornadoes.

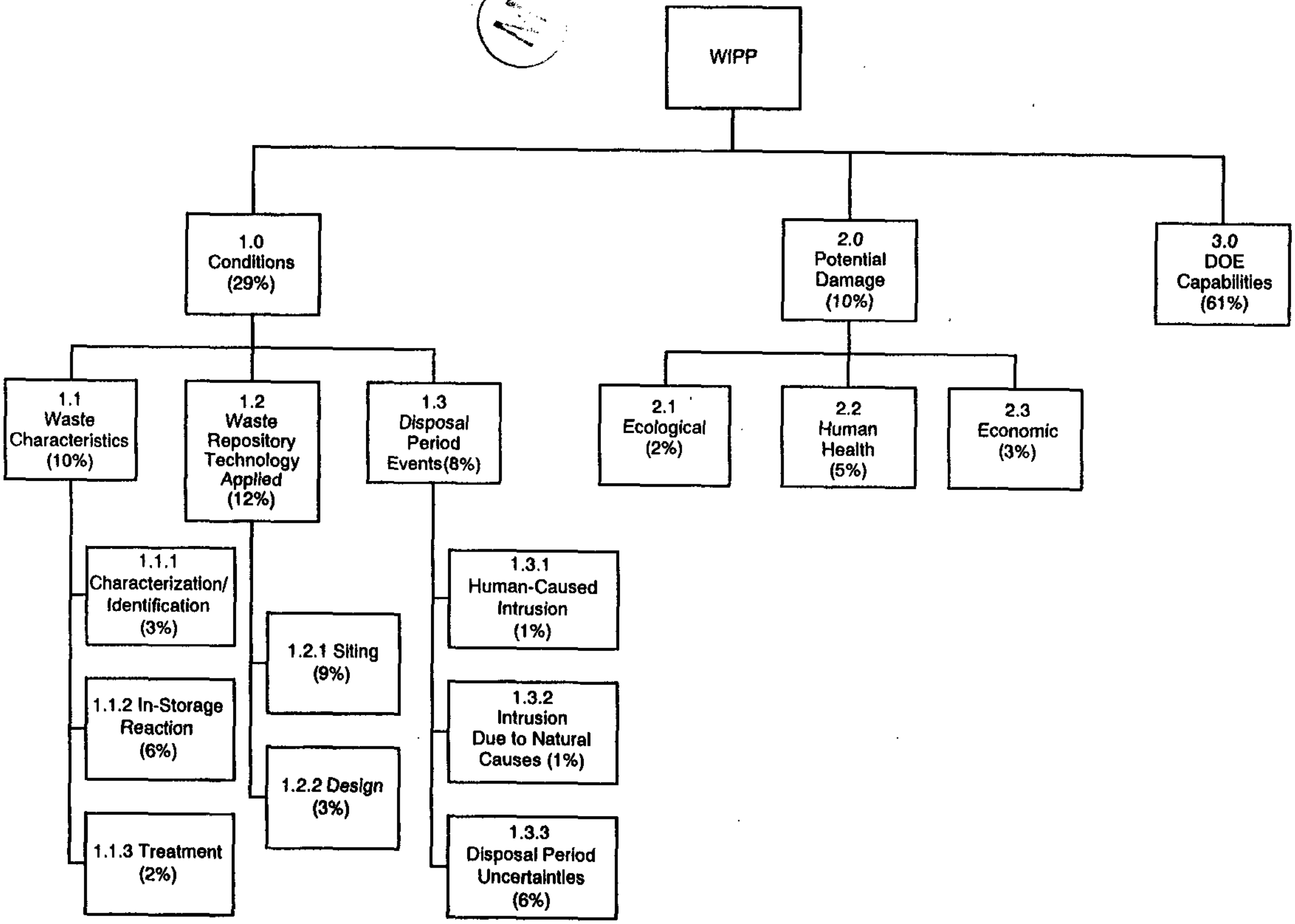

Figure 3-16
WIPP Postclosure Concerns Phase 1 Taxonomy

1.3.3 Disposal period uncertainties (10,000 years)—Standards, technology obsolescence, changes in cultural/social norms and practices, shifts in language use and meaning, unpredictable events

2.0 Potential Damage—Issues and conditions pertaining to environmental and human health and safety.

2.1 Ecological—Indigenous flora and fauna, groundwater contamination, effects on the Pecos and Rio Grande Rivers.

2.2 Human Health—Psychological impacts, medical services, radiation dose limits, radiation protection standards, exposure to plutonium.

2.3 Economy—Business development, tourism, property values, financial responsibility in event of accidental release.

3.0 DOE Capabilities—Public perceptions of DOE and its ability to manage the WIPP (e.g., credibility, impartial scientific review, needs for review and oversight).

Modifying the Comment Taxonomy for Phase 2

Focus group results indicated a need for extending and modifying the Phase 1 taxonomy so that suggested contemporary stakeholder concerns could be more adequately categorized. The original taxonomy was extended into seven major categories as shown on Figure 3-17, WIPP Postclosure Concerns Phase 2 Taxonomy, and discussed below. All Phase 1 categories are represented in the Phase 2 taxonomy. Percentages reflect relative frequency of comment by category.

Phase 2 Comment Taxonomy

1.0 Waste Conditions—Conditions seen as potential causes for undesirable outcomes.

1.1 Characterization/Identification -Radioactivity level of waste (e.g., curie level), commercial waste, hazardous wastes, hazardous chemical constituents.

1.2 In-Storage Reaction—Gas generation, heat generation.

1.3 Treatment—Vitrification, cementation.

1.4 Characteristics—Attributes (e.g., origin, volume, quantity) of the waste proposed for disposal at the WIPP facility.

2.0 Technology Applied—Aspects, appropriateness, and nature of technologies to be used at the WIPP.

2.1 Siting—Geological, hydrological aspects of the WIPP site itself.

2.2 Site Design—Plugs and seals, backfill.

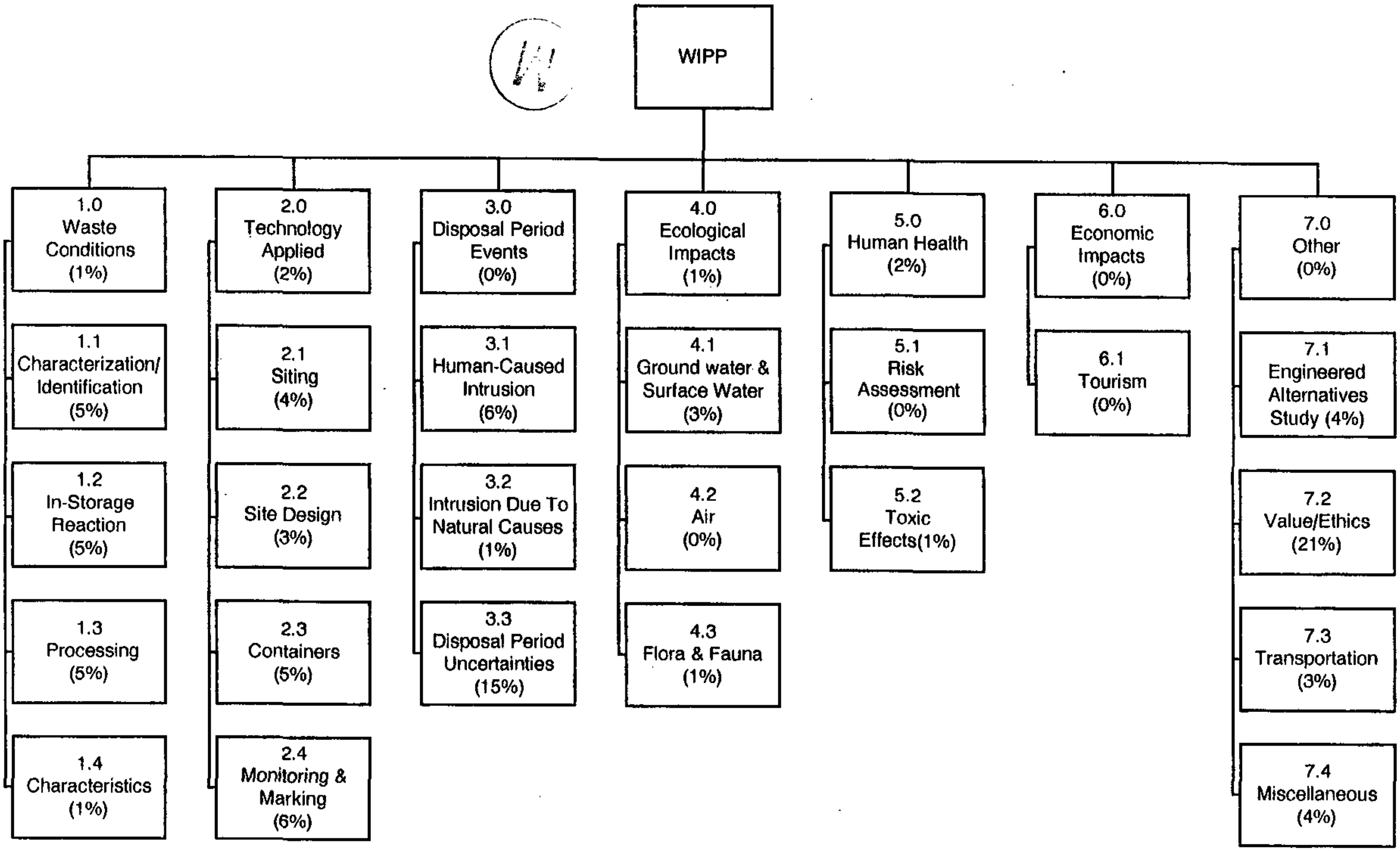

Figure 3-17
WIPP Postclosure Concerns Phase 2 Taxonomy

2.3 Containers—Permanent and temporary waste storage devices, e.g., drums, TRUPACT.

2.4 Monitoring and Marking—Matters pertaining to the short and long-term monitoring of the WIPP and/or its contents. Concerns about how WIPP can be marked such that future generations comprehend its location and purpose.

3.0 Disposal Period Events—Outcomes, regardless of cause, that could introduce adverse risk to the environment.

3.1 Human-Caused Intrusion—Planned and unplanned mining, drilling, sabotage, terrorism events.

3.2 Intrusion Due to Natural Causes—Seismic, climatic changes (e.g., substantially increased precipitation, tornadoes).

3.3 Disposal Period Uncertainties—Standards, technology obsolescence, changes in cultural/social norms and practices, shifts in language use and meaning, unpredictable events.

4.0 Ecological Impacts—Events which could result in damage to the environment, including groundwater, surface water, and plant and animal life.

5.0 Human Health—Psychological impacts, medical services, radiation dose limits, risk assessments, radiation protection standards, exposure to nuclear materials, and toxic effects.

6.0 Economic Impacts—Business development, tourism, property values, financial responsibility in event of accidental release.

7.0 Other

7.1 EA Study—Matters relating directly to this study, e.g., concerns about whether the regulations require the use of engineered alternatives.

7.2 Value/Ethics—Public perceptions of, individuals, society, and its institutions as they relate to motives, values, and actions pertaining to the public good. (e.g., credibility, impartial scientific review, need for review and oversight).

7.3 Transportation—Topics concerning the movement of waste materials via public roadways and/or other routes by motorized conveyance prior to WIPP closure.

7.4 Miscellaneous—Comments not readily associated with any other taxonomic category.

Formatting Comment Data in Phase 1

Each comment was tagged with a unique identifier. For example, "roll-up" comments from the WIPP FSEIS were already numbered. If a particular comment published in the FSEIS was identified as pertaining to postclosure WIPP, then the number of that comment was placed into one of the comment categories as defined by the taxonomy discussed above. Other comment sources were handled similarly by using either existing comment identification codes or by creating new ones when necessary. This system allows traceability from data back to the original comment as published or collected from oral presentation.

In some instances, a single recorded comment may have been made many times by different individuals. In such cases, the frequency of comment occurrence has been recorded as ***the total number of times the comment was made.*** This allows the same comment to be examined against time and frequency of occurrence. All raw data have been retained on file and may be accessed as required.

Additionally, comments have been coded by location source. For example, comment category 5.1-2 (a roll-up comment from the FSEIS) pertains to waste characterization and identification. There are 19 individual comments that form the basis for this roll-up. Fifteen of these comments were from New Mexico sources and four from outside the state. Further, data have been collected for this study that documents that fourteen of the fifteen New Mexico comments were from Santa Fe sources and one from an Albuquerque source. Geographic source data are on file.

Formatting Comment Data in Phase 2

Verbatim transcripts of the meetings were not prepared. Instead, notes were recorded on flip charts. As completed, individual sheets of notes were posted around the room. Additionally, notetakers were provided to record information to supplement that recorded on the charts. After the meeting, the meeting notes were finalized and sent to each participant for review and comment. Focus group comments are included as Appendix M.

Written comments for each meeting were analyzed and were sorted into specific taxonomic categories. In many instances, a "single" comment made by an individual at the focus group meeting consisted of comments on several subjects. For example, a participant might begin commentary by talking about perceived risks associated with groundwater intrusion into the repository, transition to a remark about how future generations might know about WIPP, and close with a statement concluding that, in the speaker's opinion, WIPP was well engineered, scientifically thorough, and ready to be put to use. Comments such as this are related to several taxonomic categories and were so recorded. When all comments had been categorized, they were then examined to determine whether they reflected a concern about postclosure WIPP or a more general concern not directly pertinent to postclosure WIPP (e.g., transportation of waste via TRUPACT-II).

3.6.2.2 Data Reduction

The number of comments occurring in each taxonomic category was converted to a percent of the total number of comments from a single source. Data in tabular form are provided in

Appendix N. Phase 1 data were combined to yield a composite of all original data sources. Phase 2 data were similarly combined for a composite view.

Phase 1 data include only comments pertaining to postclosure WIPP. Phase 2 data include more general comments about WIPP that extend beyond concerns about the postclosure period. These additional data are included to give a more accurate impression of actual focus group commentary. While the purpose of the focus group meeting was clearly stated by group leaders at the beginning of each session, discussion quite naturally extended beyond concerns about postclosure WIPP to other topics. The ratio of postclosure-specific to WIPP-general comments is perhaps a useful index of the intensity of public concern with postclosure WIPP in relation to concern about more current WIPP-related issues.

All data are presented in the body of this report as exploded pie charts. This format allows easy comparison of one data set to another. Changes were made to all sections of the Phase 1 taxonomy to accommodate specific concerns presented at the focus group discussions. Additionally, the focus group discussions concentrated on WIPP postclosure concerns. Therefore, Phase 1 and Phase 2 data are not directly comparable on a category-to-category basis. *Nonetheless, trend comparisons can be made easily. Data presented in chart form have been* intentionally limited in level of detail (this allows easier interpretation); a detailed accounting of frequency counts and percentages by category and subcategories is available in Appendix N.

3.6.2.3 Data Analysis

Raw data have been arrayed in similar formats such that major comparisons and trends may be identified. For example, much data reduction has been in terms of "percent." This practice allows rapid comparison of data sets of unequal size. There has been no attempt to apply formal analytic tools for the purpose of testing the statistical significance of this study's preliminary findings. Nonetheless, it is useful to note highly visible trends as a means for further thought and investigation.

Data were examined systematically to determine:

1. Which area is the most frequent comment category?

2. What are the sources of comments? (By state, city, etc.)

3. Have the relative frequency of comments changed over time?

4. How are public concerns about postclosure WIPP proportional to more general, contemporary WIPP issues?

5. Are there differences in comment frequencies related to geographic origin of comments?

3.6.2.4 Matching EAs to Noted Public Concerns About Postclosure WIPP

An interdisciplinary Working Group (the EASWG) of technical professionals who participated in the development of the EACBS was assembled to examine each EA and assess whether the alternative could address noted postclosure concerns. The Phase 2 taxonomy was used for this assessment as all concerns categorized in the Phase 1 taxonomy are addressed in the Phase 2 taxonomy. To ensure the Working Group understood the postclosure concerns present by the focus groups, a review was made of all notes for the focus group discussions and interviews. The Working Group did not assess the importance of the concerns, only whether the EAs could address or mitigate the noted postclosure concerns. Several assumptions were used by the Working Group in this assessment. The assumptions that were used are presented below.

- All waste processing EAs will require some level of postprocessing waste characterization.

- All waste will be assayed prior to disposal or shipment to WIPP.

- EAs were only matched to postclosure concerns.

- Sampling and analysis of headspace gas will be performed for all drums to determine the quantities of hydrogen, methane, and listed volatile organic compounds.

- All drums will undergo real-time-radiography which is a nondestructive test used to X-ray and inspect waste containers to determine the physical form of the waste and identify the presence or absence of free liquids.

- Using a statistically valid sample, a visual inspection will be performed of waste containers to ensure the level of quality for the real-time radiography inspections.

The results of this assessment are presented below. For each EA evaluated in the Cost/Benefit Study, a brief description of the alternative is presented, along with a statement of how the alternative would augment current baseline conditions/or programs for the WIPP. Many of the EAs in the Cost/Benefit Study are different combinations of waste processing techniques and/or backfill measures. For the purposes of this assessment, the waste processing techniques and types of backfills are addressed separately. The public postclosure concerns that could be addressed by the alternative are then presented by category and the total percentage of the comments that pertain to that concern are noted.

3.6.2.4.1 <u>Supercompact Waste [Alternatives #1 and #77(a-d)]</u>

Solid organic and inorganic wastes are sorted to remove items that cannot be compacted. The sorted waste is precompacted into 35-gallon drums and the supercompacted sludges are not processed.

<u>Public Concerns Which May Be Addressed by this Alternative</u>

This EA cannot be used for all waste streams. Some sorting and visual inspection of the waste is performed for this alternative which will augment the waste characterization process that is used to ensure that waste meets the WIPP WAC. Therefore, concerns regarding waste characterization/identification (5%), could be addressed by this alternative. Additionally, as the alternative would increase the density and strength of the waste form that would be emplaced in the repository, the potential release of hazardous and radioactive materials that could result from human-caused intrusions would be mitigated. Public concerns regarding human-caused intrusions (6%), disposal period uncertainties (15%), ecological impacts (1%), engineered alternatives (4%), and human health (2%) could therefore be mitigated by this alternative.

3.6.2.4.2 Shred and Compact Solid Organic and Solid Inorganic Waste (Alternative #6)

Solid organic and inorganic wastes are shredded and compacted into 55-gallon (208-liter) drums using a lower pressure compactor than in supercompaction. Sludges are not processed.

Public Concerns Which May Be Addressed by this Alternative

This EA cannot be used for all waste streams. Some sorting and visual inspection of the waste is performed for this alternative which will augment the waste characterization process that is used to ensure that waste meets the WIPP Waste Acceptance Criteria. Therefore, concerns regarding waste characterization/identification (5%) could be addressed by this alternative. Additionally, as the alternative would increase the density and strength of the waste form that would be emplaced in the repository, the potential release of hazardous and radioactive materials that could result from human-caused intrusions would be mitigated. Public concerns regarding human-caused intrusions (6%), disposal period uncertainties (15%), ecological impacts (1%), engineered alternatives (4%), and human health (2%) could therefore be mitigated by this alternative.

3.6.2.4.3 Treat All Waste in a Plasma Melter (Alternative #10)

All wastes are processed through a shredder and the input waste stream is regulated to ensure a suitable metal to waste ratio. The waste is processed through a Plasma Arc Centrifugal Treatment system and poured into 55-gallon (208-liter) drums.

Public Concerns Which May Be Addressed by this Alternative

This EA can be used for all waste streams. In addition to the waste characterization that will be performed for all WIPP waste, some sorting and visual inspection of the waste is performed for this alternative. Therefore, concerns regarding waste characterization/identification (5%), could be addressed by this alternative. Additionally, as the alternative would destroy the hazardous organic constituents in the waste, concerns pertaining to the release or migration of hazardous constituents would be addressed. The alternative would also increase the density and strength of the waste form that would be emplaced in the repository, thus the potential release of hazardous and radioactive materials that could result from human-caused intrusions would be reduced. Thus, public concerns regarding waste processing (6%), waste characteristics (1%), human-caused intrusions (6%), disposal period uncertainties (15%), ecological impacts (1%), engineered alternatives (4%), and human health (2%) could be mitigated by this alternative.

3.6.2.4.4 Sand Plus Clay Backfill (Alternative #33)

A mixture of medium grained sand and granulated clay is used as a backfill for this alternative. The mixture is placed around the waste stack and between the drums filling the void space in the rooms within the repository.

Public Concerns Which May Be Addressed by this Alternative

This sand/clay backfill will lower the permeability and porosity of the waste, thus reducing the potential for release of contaminated brine through a drilling event. It will also limit brine inflow, thus reducing gas generation. Therefore, this alternative addresses concerns regarding in-storage reactions (5%), human-caused intrusions (6%), site design (3%), disposal period uncertainties (15%), engineered alternatives (4%), ecological impacts (1%), and human health (2%).

3.6.2.4.5 Salt Aggregate Grout Backfill (Alternative #35a)

This EA uses a salt aggregated grout mixture as backfill to fill the void spaces within a room in the repository after the waste is emplaced. This backfill consisting of a cementitious-based grout (which uses crushed salt as the aggregate and simulated WIPP brine as the added water), is pumped around the waste stack and between the drums filling the void space within the rooms.

Public Concerns Which May Be Addressed by this Alternative

Salt aggregate grout backfill increase the pH of any brine that may come in contact with the waste, thereby reducing gas generation and radionuclide solubility and mobility. This backfill also lowers the permeability and porosity of the waste, which minimizes brine inflow. Public concerns which may be mitigated by this alternative include those regarding in-storage reactions (5%), human-caused intrusions (6%), site design, (3%), disposal period uncertainties (15%), engineered alternatives (4%), ecological impacts (1%), and human health (2%).

3.6.2.4.6 Cementitious Grout Backfill (Alternative #35b)

A cementitious based grout backfill consisting of ordinary Portland cement, sand aggregate, and fresh waster is used for this alternative. The backfill is pumped around the waste stack and between the drums filling the void space within the room.

Public Concerns Which May Be Addressed by this Alternative

This backfill will increase the pH of any brine that may come in contact with the waste, thereby reducing gas generation and radionuclide solubility. This backfill also lowers the permeability and porosity of the waste, which minimizes brine inflow. Public concerns which may be mitigated or addressed by this alternative include those regarding in-storage reactions (5%), human-caused intrusions (6%), site design (3%), disposal period uncertainties (15%), engineered alternatives (4%), ecological impacts (1%), and human health (2%).

3.6.2.4.7 Lime (CaO) and Crushed Salt Backfill (Alternative #83)

This backfill consists of a commercially available granulated lime (quick lime) and crushed salt aggregate which is pneumatically placed around the waste stack and between the drums, filling the void space in the rooms. The mixture consists of less than 10% lime and 90% crushed salt aggregate.

Public Concerns Which May Be Addressed by this Alternative

The introduction of lime to the backfill increases the pH of any brine that may come in contact with the waste in the repository, thereby reducing radionuclide solubility and mobility. Lime backfill also lowers the permeability and porosity of the waste, which minimizes brine inflow. Public concerns which may be mitigated or addressed by this alternative include those regarding in-storage reactions (5%), human-caused intrusions (6%), site design, (3%), engineered alternatives (4%), disposal period uncertainties (15%), ecological impacts (1%), and human health (2%).

3.6.2.4.8 Enhanced Cementation of Sludges, Shred and Add Clay to Solid Organic and Solid Inorganic Wastes [Alternatives #94(a-f)]

This alternative includes two processes to treat the waste: (1) enhanced cementation of previously solidified and as generated sludges and (2) shredding solid organic and inorganic waste and adding clay to the shredded waste. Existing sludges are fed into a crusher/shredder. The crushed waste is mixed with an enhanced cement and is poured into 55-gallon (208-liter) drums. Newly generated sludges that are not dried will be solidified with the enhanced cement.

Solid organics and inorganics are shred and clay is added to the waste. This waste is packaged in 55-gallon (208-liter) drums.

Public Concerns Which May Be Addressed by this Alternative

This EA can treat both sludges and solid inorganic and organic waste. In addition to the waste characterization that is performed to meet the WIPP Waste Acceptance Criteria, some sorting and visual inspection of the waste is performed prior to shredding. Therefore, noted public concerns regarding waste characterization/identification (5%) could be mitigated by this alternative. This alternative will also reduce the generation of gas by increasing the pH of brine that may come into contact with the waste form. Thus, concerns about in-storage reactions (5%) would be mitigated by this alternative. Additionally, the alternative will reduce brine inflow through the addition of clay-based materials to the waste, therefore, the potential release of hazardous and radioactive materials that could result from human-caused intrusions would be reduced. Thus, public concerns regarding waste processing (5%), waste characteristics (1%), human-caused intrusions (6%), disposal period uncertainties (13%), ecological impacts (1%), engineered alternatives (4%), and human health (2%) could be addressed or mitigated by this alternative.

3.6.2.4.9 Clay-based Backfill (Alternative #111)

A backfill consisting of commercially available pelletized clay will be used for this alternative. The clay backfill will be placed around the waste stack and between the drums filling the void pace within the rooms.

Public Concerns Which May Be Addressed by this Alternative

The clay backfill will reduce the hydraulic conductivity of the backfill and impede the flow of brine and the mobility of radionuclides. This alternative may therefore address or mitigate public concerns regarding in-storage reactions (5%), human-caused intrusions (6%), site design (3%), disposal period uncertainties (15%), ecological impacts (1%), engineered alternatives (4%), and human health (2%).

3.6.2.4.10 Public Concerns That Could Not be Addressed by an EA

The EAs that are assessed in this Cost/Benefit Study could not address all postclosure concerns that were noted during this study. The categories of public concerns that could not be addressed or reduced by an EA include siting (4%), containers (5%), monitoring and marking (6%), intrusion due to natural causes (1%), economic impacts (0%), values and ethics (21%), and miscellaneous (4%).

3.6.3 Results of Analysis

3.6.3.1 Comments on the WIPP FSEIS, 1990

Figure 3-18, Relative Frequency of Comments by Category for the WIPP FSEIS, is a graphical representation of the comments by category.

1. *Most comments fell into the "DOE Capabilities" category.*

   Sixty-three percent (4,154 out of 6,539) of all postclosure WIPP comments pertained to perceptions of DOE as they related to DOE's ability to manage the WIPP (Figure 3-18). Comments included concerns about credibility, scientific impartiality, and need for proper review and oversight. The percentage of comments falling into this category decreases in other comment sources made at later dates.

2. *The majority of comments were from New Mexico residents.*

   Of the 1,591 total postclosure oral comments on the WIPP FSEIS, 1,417 (89%) were comments made by New Mexicans. Total written comments on the WIPP SEIS numbered 4,948 with 4,412 (89%) being from New Mexicans.

3. *The rank ordering of comment categories and subcategories by number of comments recorded reveals that New Mexican and non-New Mexican commenters alike tended to place importance on the same issues.*

   A comparison of total comment frequency to comment frequency attributed to New Mexicans showed no rank order position differing by more than one.

4. *Public concerns are approximately equally balanced among the categories within "Conditions."*

   Concerns about "Waste Characteristics" total 10% while concerns about "Waste Repository Technology Applied" total 12% and concerns expressed about "Disposal Period Events" total 8%.

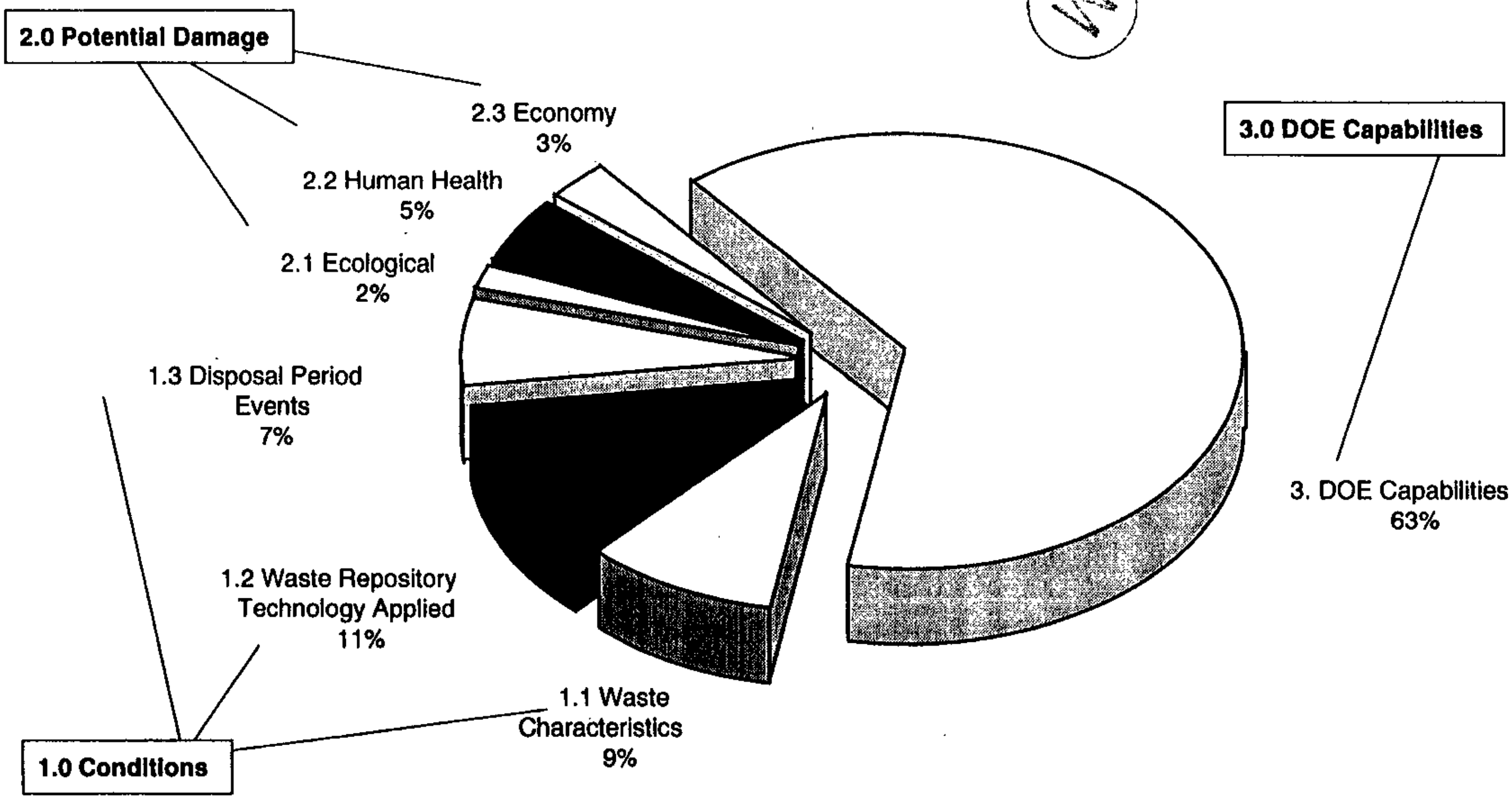

Figure 3-18
Relative Frequency of Comments by Category
WIPP Supplement Environmental Impact Statement
n = 6,539

3.6.3.2 Comments on 40 CFR Part 191, December 1993

Figure 3-19 illustrates relative frequency of comments by category for the December 1993 responses to the Amendments for 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Wastes.

1. *Comments directly related to DOE capabilities were 2% of the total.*

2. *The comment category of more frequent concern was "Conditions" (85%).*

3. *The most frequent comment category within "Potential Damage" pertained to potential human health effects of the repository (10% of a total 13%).*

3.6.3.3 Comments on Proposed Rule 40 CFR Part 194, March 21-24, 1995

Figure 3-20 shows the relative frequency of comments by category for the March 21-24, 1995, public hearing on the EPA's Proposed Rule 40 CFR Part 194.

1. *The majority of comments pertained to "Conditions" (81%).*

2. *Within the category "Conditions," most comments were directed toward applied waste repository technology and disposal period events (38% and 26% respectively). The third subcategory, "Waste Characteristics," accounted for 17% of the total.*

3. *Comments regarding potential damage (human health, ecological, and economic) accounted for a total of 13% of all comments.*

3.6.3.4 Comments from Carlsbad Focus Group Discussion and Interviews

Figure 3-21 provides the relative frequency of comments for the focus group discussions held in Carlsbad, New Mexico.

1. *The largest percentage of comments fell under "Other." By reference to Appendix N, the single largest subcategory of comments is "Value/Ethics."*

2. *"Economic Impacts" had the least number of total comments (2%).*

3. *Comments pertaining to "Disposal Period Events" constitute 12% of all comments.*

3.6.3.5 Comments from Albuquerque Focus Group

Figure 3-22 illustrates the relative frequency of comments for the Albuquerque focus group.

1. *As with the Carlsbad focus group, Albuquerque results show the majority of comments (34%) falling into the category "Other." Again, the data in Appendix N help clarify this finding. Within this category, comments concerning "Value/Ethics" dominate (19%), with the remaining portion mostly concerning the EA Study (10%).*

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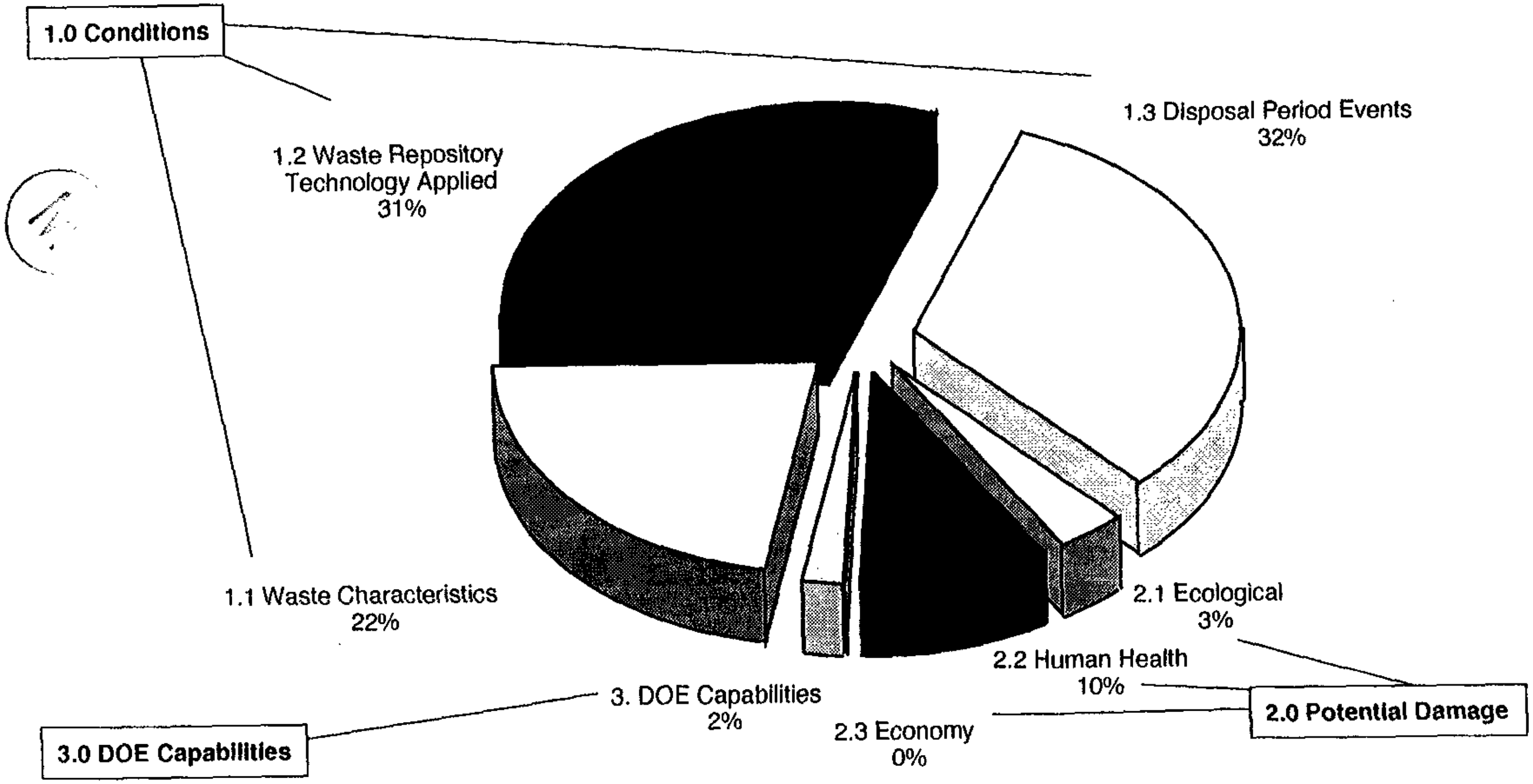

Figure 3-19
Relative Frequency of Comments by Category
Response to Amendments for 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes, December 1993
n = 157

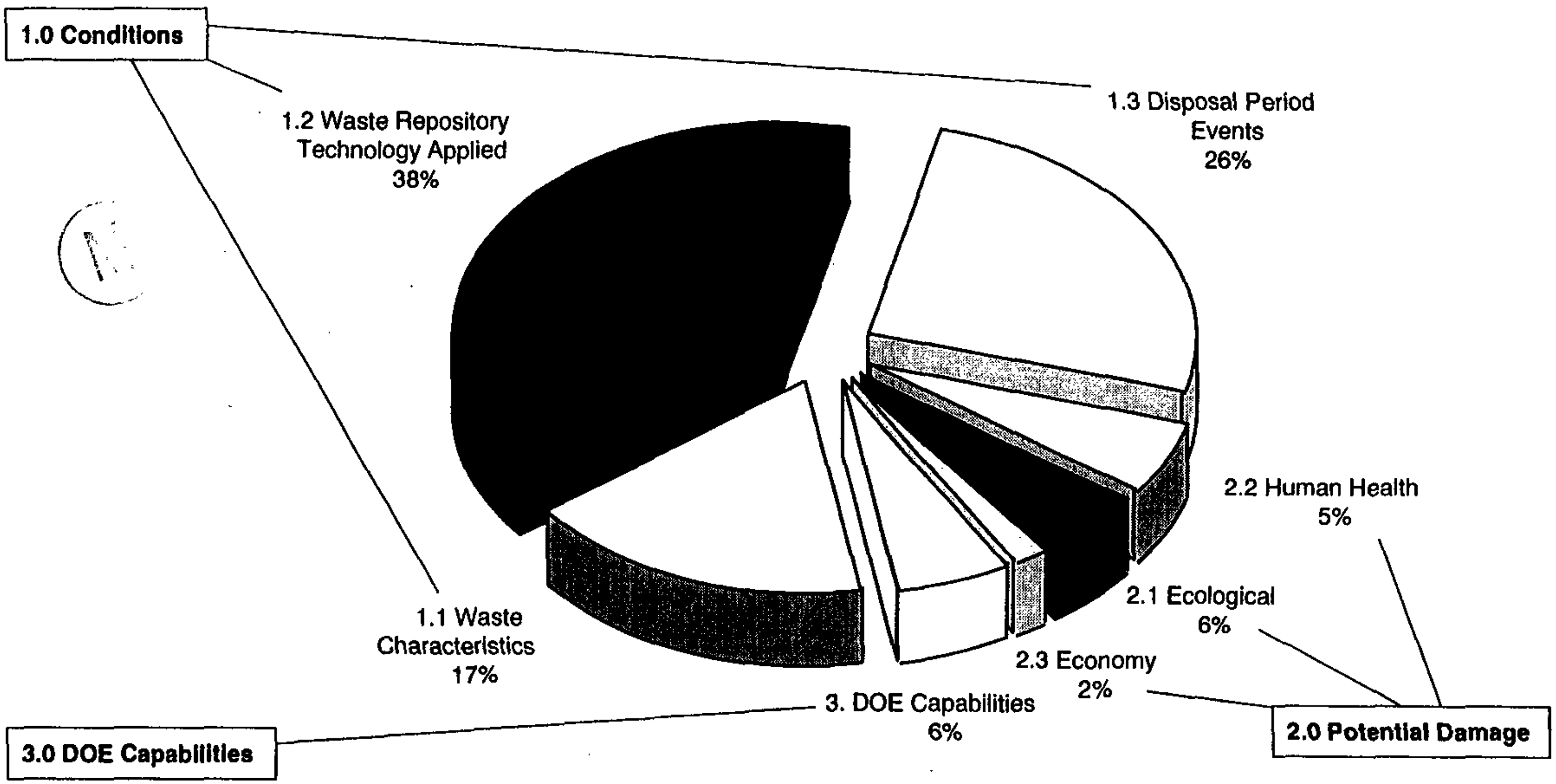

Figure 3-20
Relative Frequency of Comments by Category
Public Hearings on EPA's Proposed Rule 40 CFR Part 194, March 21-24, 1995
n = 181

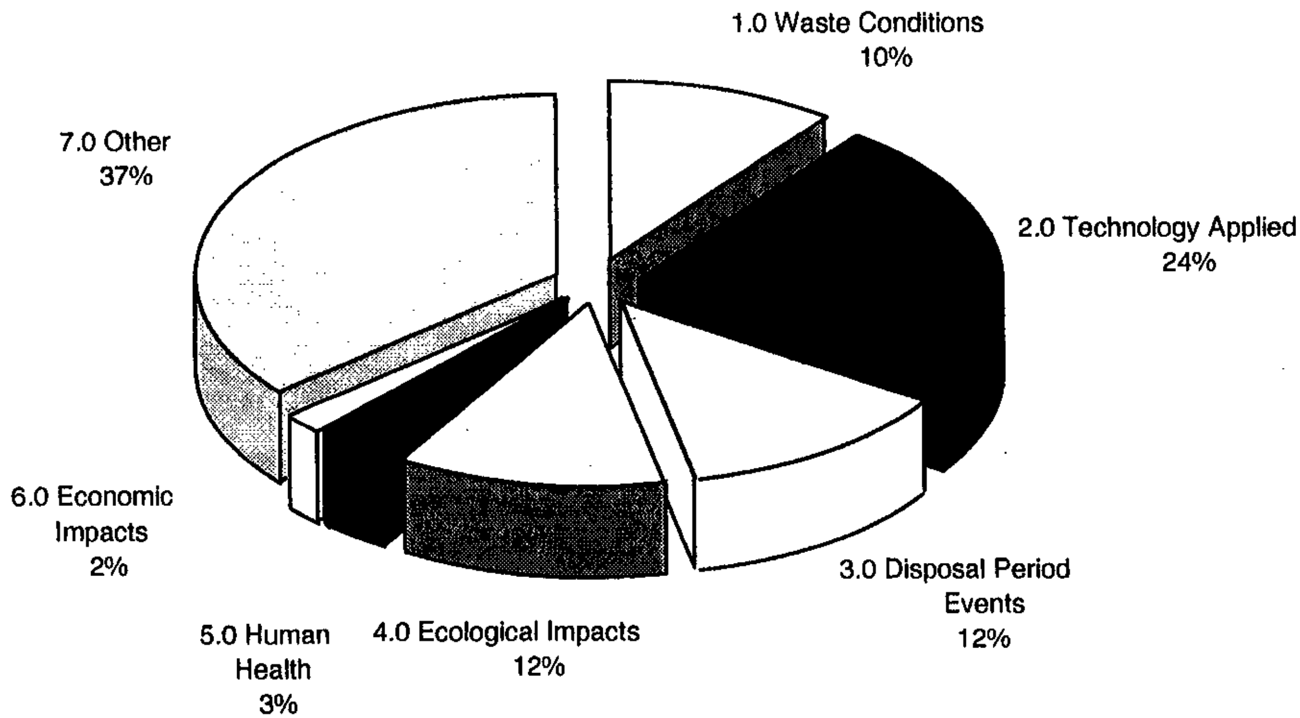

Figure 3-21
Relative Frequency of Comments by Category
Focus Group Meetings – June 1995
Carlsbad
n = 58

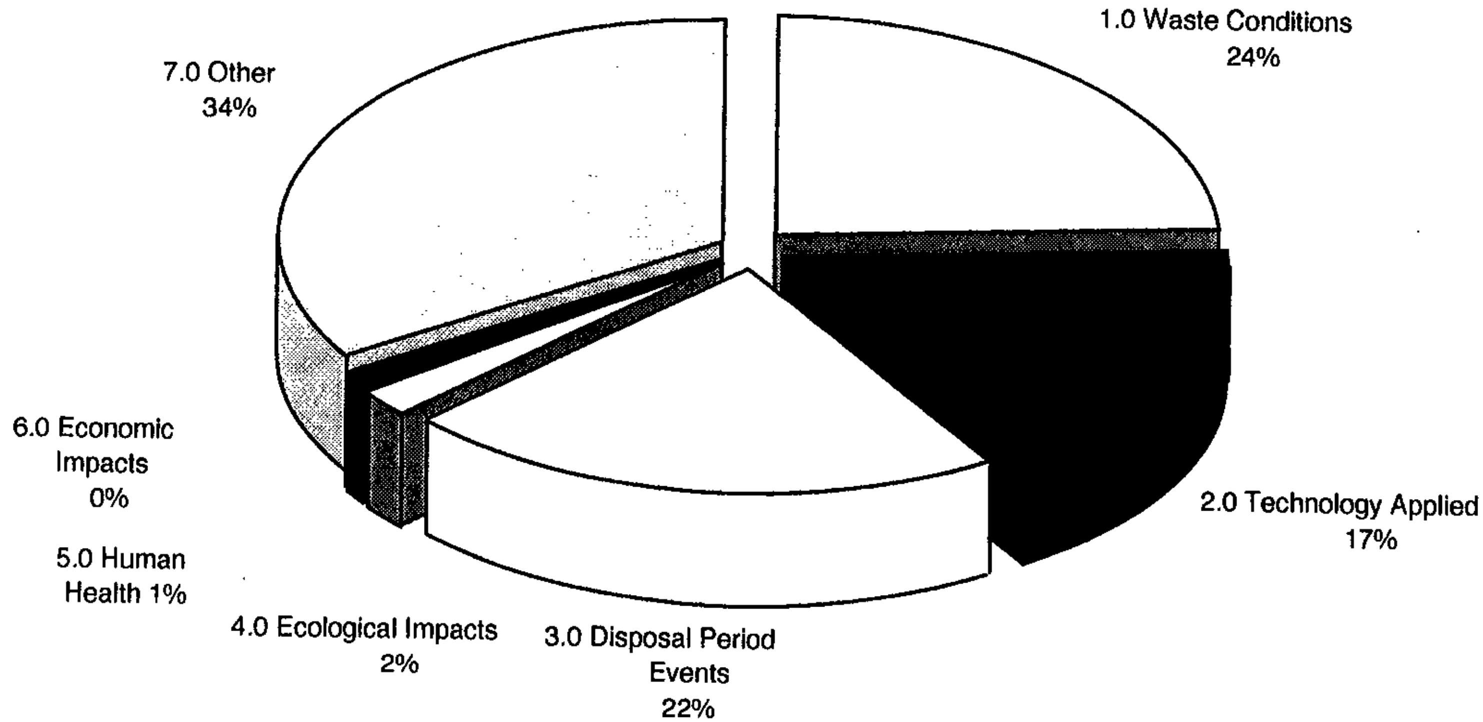

Figure 3-22
Relative Frequency of Comments by Category
Focus Group Meetings – June 1995
Albuquerque
n = 105

2. *Twenty-two percent of all comments were related to issues surrounding disposal period events, with 11% relating to "Disposal Period Uncertainties" and 11% concerned with "Human-Caused Intrusion."*

3.6.3.6 Comments from Santa Fe Focus Group Discussion and Interview

Figure 3-23 illustrates the relative frequency of comments for the focus group discussions held in Santa Fe, New Mexico.

1. *The majority of comments are again in the category of "Other" (28%). Examination of detail data in Appendix N reveals that 22% of the comments pertained to "Value/Ethics" with the remaining 5% fairly evenly distributed over the remaining three subset categories, "Engineered Alternatives Study," "Transportation," and "Miscellaneous.".*

2. *Comments pertaining to "Waste Conditions," "Technology Applied," and "Disposal Period Events" constitute 60% of all comments made during the focus group discussion. A review of actual comments in Appendix M helps to further explain the concerns.*

3.6.3.7 Data Comparison for Phase 1 Data

Figure 3-24, Relative Frequency of Comments by Category, Total All Comments, graphically represents the combined Phase 1 public concerns.

1. *Comment frequencies tend to follow the same pattern from one comment source to another.*

   The highest percentage of comments fell into the "Conditions" category (e.g., comments concerning "Waste Characteristics, Waste Repository Technology, and Disposal Period Events"). The range for this category was 58 percentage points (with a maximum value of 83% and a minimum of 25%), and the mean was 58%. A visual examination of the charts makes this observation more apparent. Other categories also tend to conform to this observation.

2. *The percentage of comments pertaining to Category 3 ("DOE Capabilities") has dropped markedly over time.*

   The 1990 SEIS recorded 4,154 comments pertaining to issues related to DOE capabilities. This represented 64% of the total 6539 comments recorded in the SEIS. The percentage of comments from other, more recent, Phase 1 sources ranged from 2% to 6%. Even though the number of comments from the other two sources totaled only 338 in comparison to the 6,539 comments from the SEIS, there seems to be a definite downward trend in this category.

3.6.3.8 Data Comparison for Phase 2 Data

Figure 3-25, Relative Frequency of Comments by Category, Focus Group Discussions and Interviews, is a composite pie chart illustrating the combined results for the focus group discussions and interviews held at Carlsbad, Santa Fe, and Albuquerque.

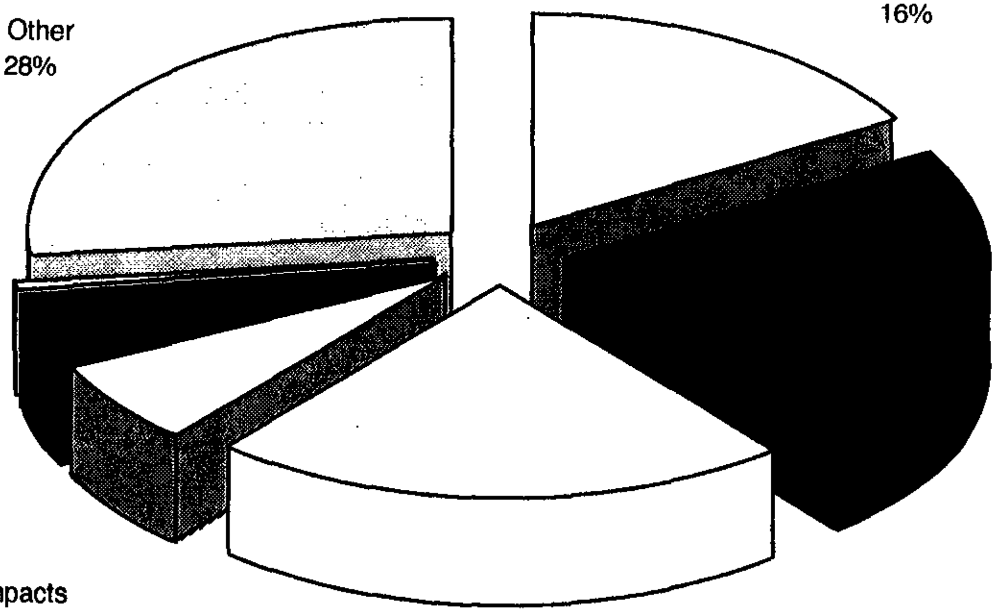

Figure 3-23
Relative Frequency of Comments by Category
Focus Group Meetings – June 1995
Santa Fe
n = 178

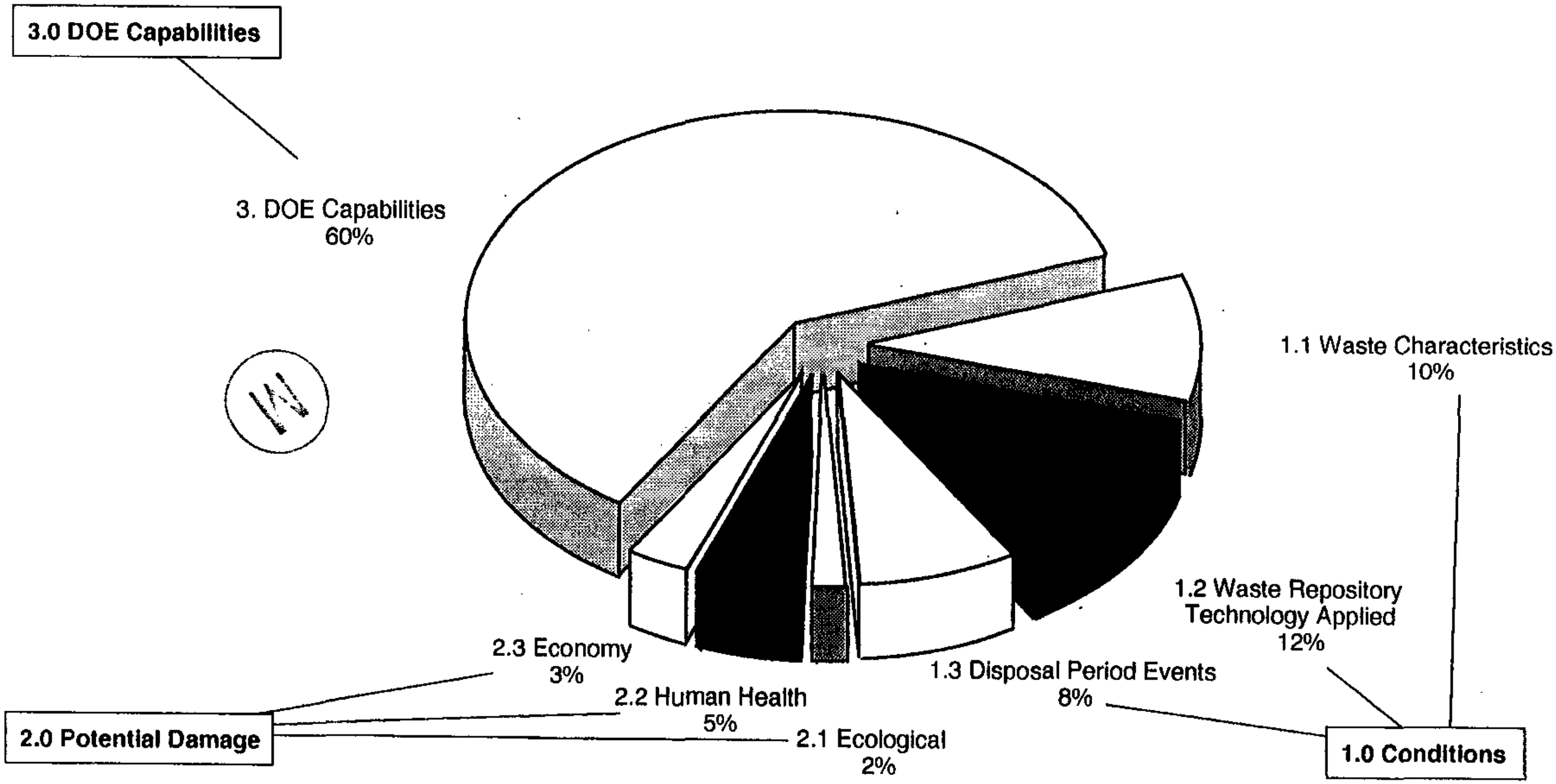

Figure 3-24
Relative Frequency of Comments by Category
Total All Comments
n = 6,877

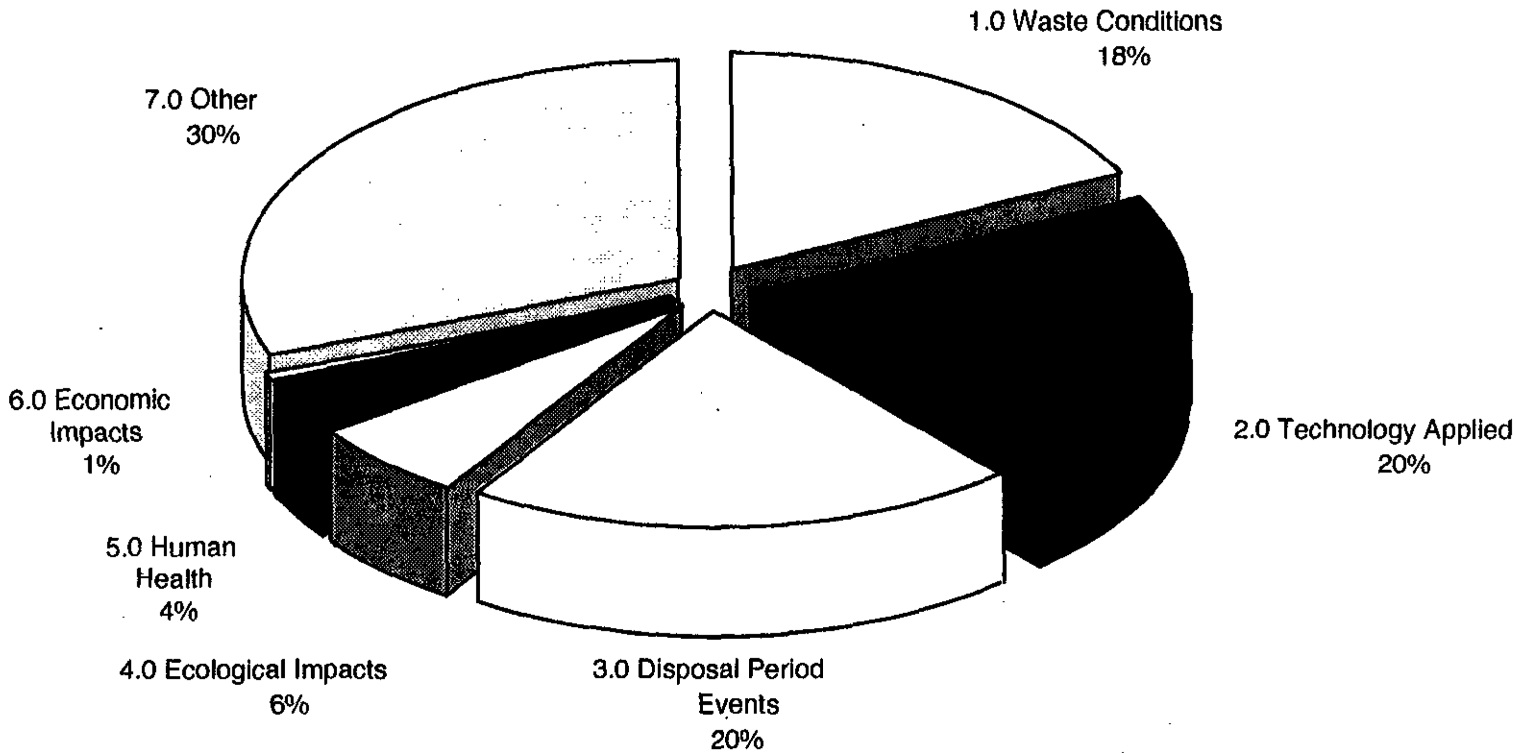

Figure 3-25
Relative Frequency of Comments by Category
Focus Group Discussions and Interviews
Composite: Carlsbad + Santa Fe + Albuquerque
n = 341

1. *Every comment made during a focus group discussion was categorized as either pertinent or not pertinent to postclosure WIPP. Interestingly, most comments made were pertinent to postclosure WIPP (ranging from 83% of all comments made on human health to 95% of all comments concerning disposal period events). The two taxonomic categories having the least percentage of comments that related directly to postclosure WIPP were "Economic Impacts" (0%) and "Other" (48%). The low percentage of postclosure-related comments in the "Economic Impact" category has little or no significance because there were only two comments made during the entire series of focus group sessions. The lower percentage of comments relevant to postclosure WIPP in the category "Other" is attributable to a host of comments made about values and ethics directed at matters of trust (see "DOE Capabilities" in the Phase 1 taxonomy). In any case, almost half of the comments included in the "Other" category cannot be regarded as comments directed specifically at postclosure WIPP. See Appendix N for detailed information on how comments were classified as pertinent or not pertinent.*

2. *"Disposal Period Events" received 20% of total comments. The very long safekeeping period required for wastes emplaced at the WIPP is a time period well beyond the predictive range commonly used by most people.*

3. *A total of only 11% of comments were classified into the categories "Economic Impacts," "Human Health," and "Ecological Impacts."*

4. *Next to concerns about "Disposal Period Uncertainties," "Technology Applied" (20% of all focus group comments) and "Waste Conditions" (18% of all comments) gathered the most comments. These comments included concerns about waste containers, the types of waste to be accepted at WIPP, waste characterization, and the technologies appropriate for long-term isolation of the waste.*

3.6.3.9 Concluding Remarks

While not a statistically pure undertaking, results of this study are several:

- The majority (78%) of the concerns presented during the focus group discussions pertained to postclosure WIPP.

- The majority of the categories of concerns can be addressed or mitigated by an EA. Only seven of the eighteen categories of concern cannot be addressed or mitigated by an EA.

- The largest single category of concern for all focus group discussions was value/ethics. Comments in this category include concerns about how decisions are made and whose values are used by the government in its decision-making practices.

- Tabular frequency analysis allows traceability of study results back to the original source of comment.

- The raw data offer expanded opportunity for more detailed examination as interest and need dictate (e.g., geographic source of comments).

Anecdotal results include the fact that each focus group discussion varied in the expressed concerns. Most of the stakeholders who participated in the Carlsbad discussions expressed their confidence in the long-term ability of the WIPP to isolate hazardous wastes from the environment. Several of the Carlsbad participants stated that they didn't really have any serious postclosure concerns about WIPP but were mildly concerned about issues such as long-term record keeping and permanent site markers. Many of the Albuquerque participants commented on the regulatory requirements for EAs, human-caused intrusion, and disposal period uncertainties. The Santa Fe participants commented on waste processing, disposal period uncertainties, monitoring and marking of the site, and how and whose values are used by the government in its decision-making practices.

There were also several comments presented during each focus group discussion which expressed concern about the adequacy of 55-gallon (208-liter) drums as waste containers, and the ecological impacts of water breaching the site, becoming contaminated, and migrating to the surface or to the overlying water-bearing strata.

3.7 FACTOR 7: DOE TOTAL SYSTEMS COST AND SCHEDULE ESTIMATES

3.7.1 Definition of Factor 7

The impact of cost and schedule for each alternative will be an important tool for planning the implementation of an alternative. Cost and schedule will typically determine the level of funding that must be appropriated, the required manpower for the activities, and a schedule that provides conceptual start and stop dates.

The total cost will be composed of waste processing, transportation, repository backfill, and emplacement handling costs for the selected alternatives in different configurations. Processing cost are estimated by first developing process flow diagrams that segment the alternative into functional elements. The costs for the alternatives are developed on the basis of waste quantities and throughput rates required to meet schedule constraints. The throughputs for each element are used to determine costs for each element, and total processing costs consist of a summation of each appropriate element cost. Other cost elements (transportation, backfill, and emplacement handling) will be estimated using accepted departmental methods. The presentation of total costs *will include a comparative analysis of the incremental change of the screened alternatives relative* to the repository baseline cost.

The schedule for each alternative will provide a measure of the alternative's desirability. An alternative with an excessive implementation schedule may be deemed undesirable. The schedule analysis provides a measure of time required to implement an EA relative to the baseline. The schedule will include a baseline and the incremental change of an alternative to the baseline.

Both cost and schedule impacts will be based on an approach consistent with current departmental methodologies and assumptions. The results of the analysis are presented according to key elements and summarized according to each alternative.

3.7.2 Methodology Used to Evaluate Factor 7

Costs estimates for implementing the individual EAs in the different facility configurations were composed of four major elements:

- Waste processing costs (Section 3.7.2.1)
- Transportation costs (Section 3.7.2.2)
- Backfill emplacement costs (Section 3.7.2.3)
- Waste emplacement handling costs (Section 3.7.2.4).

Each of these elements was summed to arrive at a total system cost.

3.7.2.1 Process Costing Methodology

The waste processing costs were estimated using information contained in "Interim Report: Waste Management Facilities Cost Information for Transuranic Waste" (WMFCITRUW) (Feizollahi and Shropshire, 1994). *The cost estimating method used by Feizollahi and Shropshire involves* segmenting waste management facilities into discrete modules which are used to estimate the costs for building and operating facilities to perform various waste management functions. Cost estimates for different types of integrated TRU waste facilities are created by linking modules for different functions together in such a way that they closely approximate an actual waste management facility. This methodology provides the flexibility to estimate the costs many different sized facilities with many different functions without having to perform a rigorous conceptual design and cost estimate for each facility configuration.

Figure 3-26 shows the information flow diagram used to develop waste processing cost estimates. Information from process flow diagrams and mass flow rates are required as input to the cost modules. A combination of data sources were used to develop this information, including existing waste inventories and waste generation projections (Appendix O), processing schedules (Appendix Q), a listing of EAs that require waste processing (Section 2), and the system configuration for the waste processing facilities (i.e., centralized, regionalized, or decentralized) (Section 2).

Process flow diagrams were developed for each alternative in each configuration (see Figures 3-27 to 3-37). These flow schemes were based on the DOE "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force" (DOE, 1991a), the Draft EM-PEIS report, and the WMFCITRUW report (Feizollahi and Shropshire, 1994). Information from these sources were used to connect each of the modules and to construct a visual description of mass and volume flow through each treatment process.

The modules are described below:

- Front End: Front-end support facilities consist of all administrative and laboratory buildings required for the waste management support functions. Front-end support functions include security, personnel decontamination (radioactive and hazardous), maintenance of noncontaminated areas and equipment, health physics, radiation badges, facility access control, sanitary facilities, work control and personnel support, internal and external communications, spill or emergency response provisions (hazardous and radioactive), analytical laboratory, environmental field sampling, environmental regulatory reporting, and records management.

- Retrieval: This module consists of all-weather excavation, inspection, and repackaging of bermed waste. The module includes three principal unit operations: earthen-cover extraction and decontamination, waste-container retrieval and inspection, and packaging and staging for shipment.

- Waste Characterization: This module is a self-contained facility in which waste characterization is performed. Activities include extracting physical samples of waste; conducting chemical, physical, and radiological analysis of waste samples; and repackaging drums and boxes to remove and stabilize noncompliant waste.

- Maintenance: A maintenance facility is used in conjunction with treatment facilities. It consists of a failed-equipment receiving and repair building housing machinery and tools.

- Treatment: The treatment module varies based on the alternative being considered. Treatment options include grouting, supercompacting, shredding and

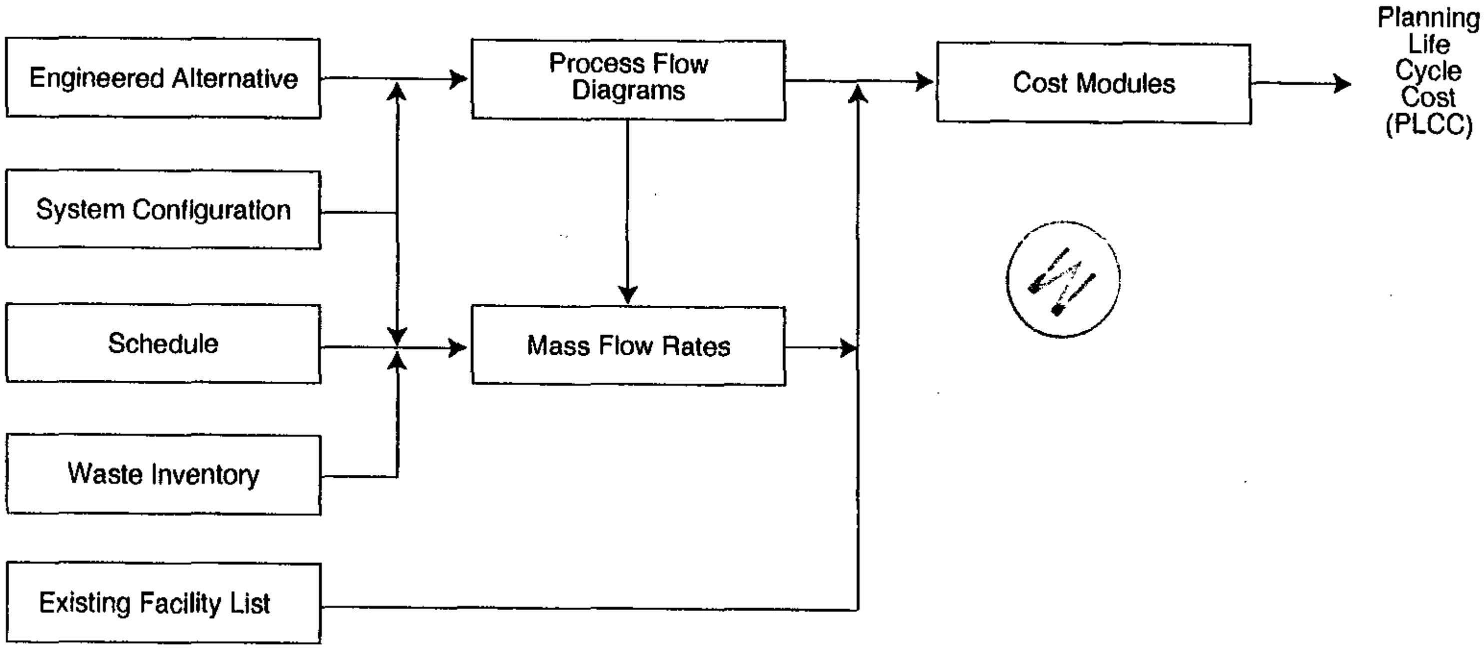

Figure 3-26

Process Costing Methodology Flow Diagram

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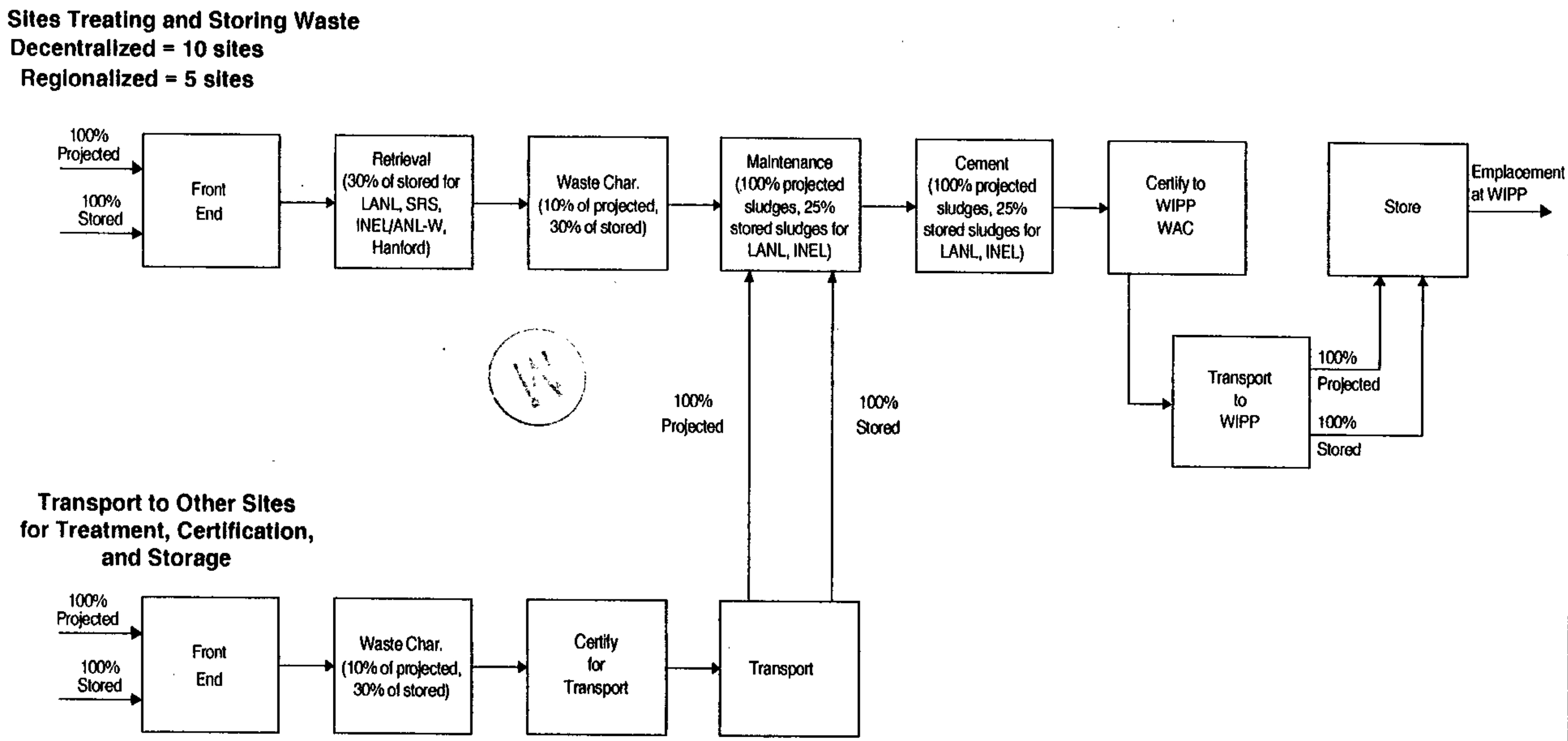


Figure 3-27
Decentralized and Regionalized Base Cases and Alternative ID #s 33, 35(a&b), 83, and 111 Contact Handled Process Flow Diagram A

DOE/WIPP 95-2135 10/13/95

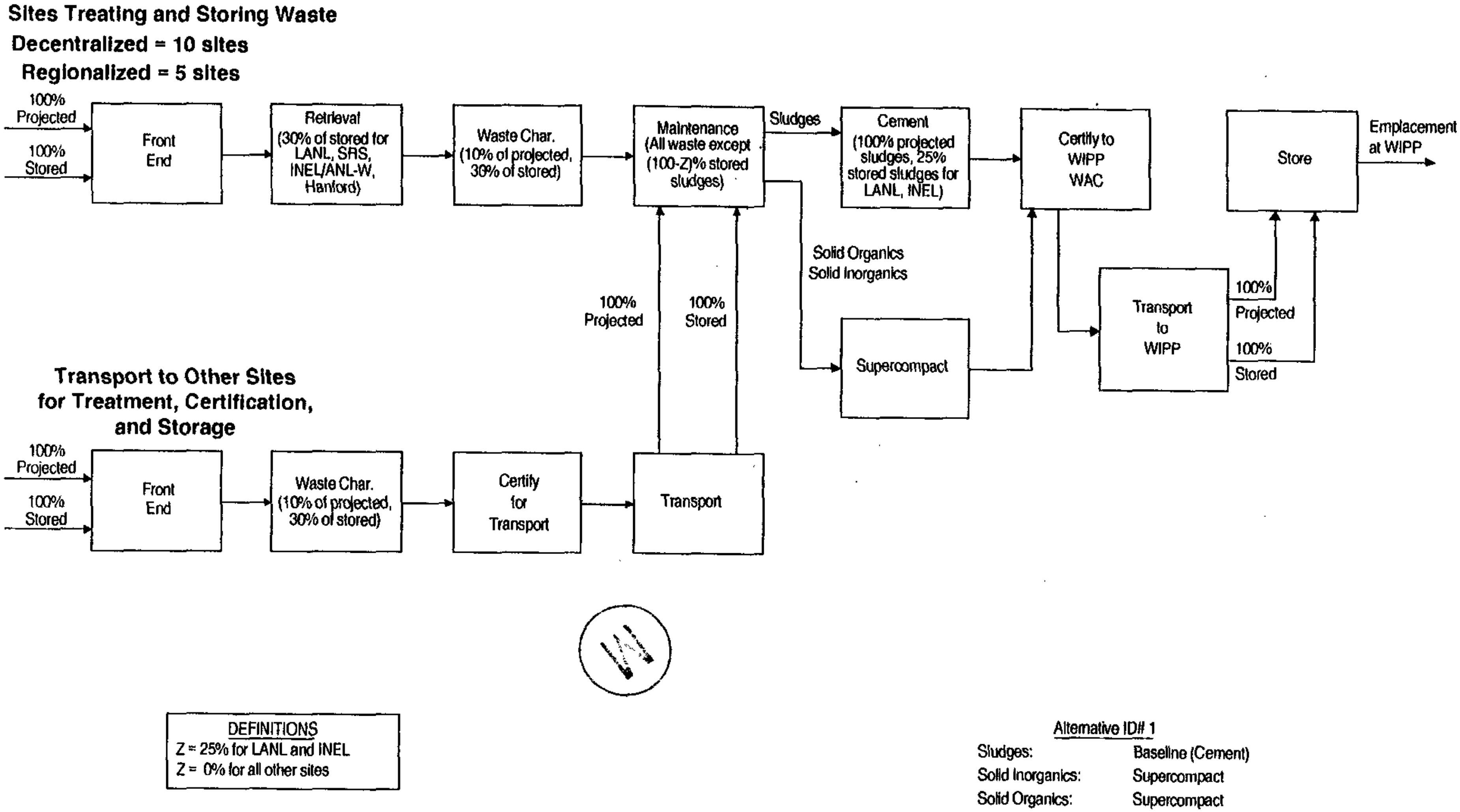


Figure 3-28

Decentralized and Regionalized Alternative ID #s 1 and 77(a-d) Contact Handled Process Flow Diagram B

763435.01.00.00.00/zc A90

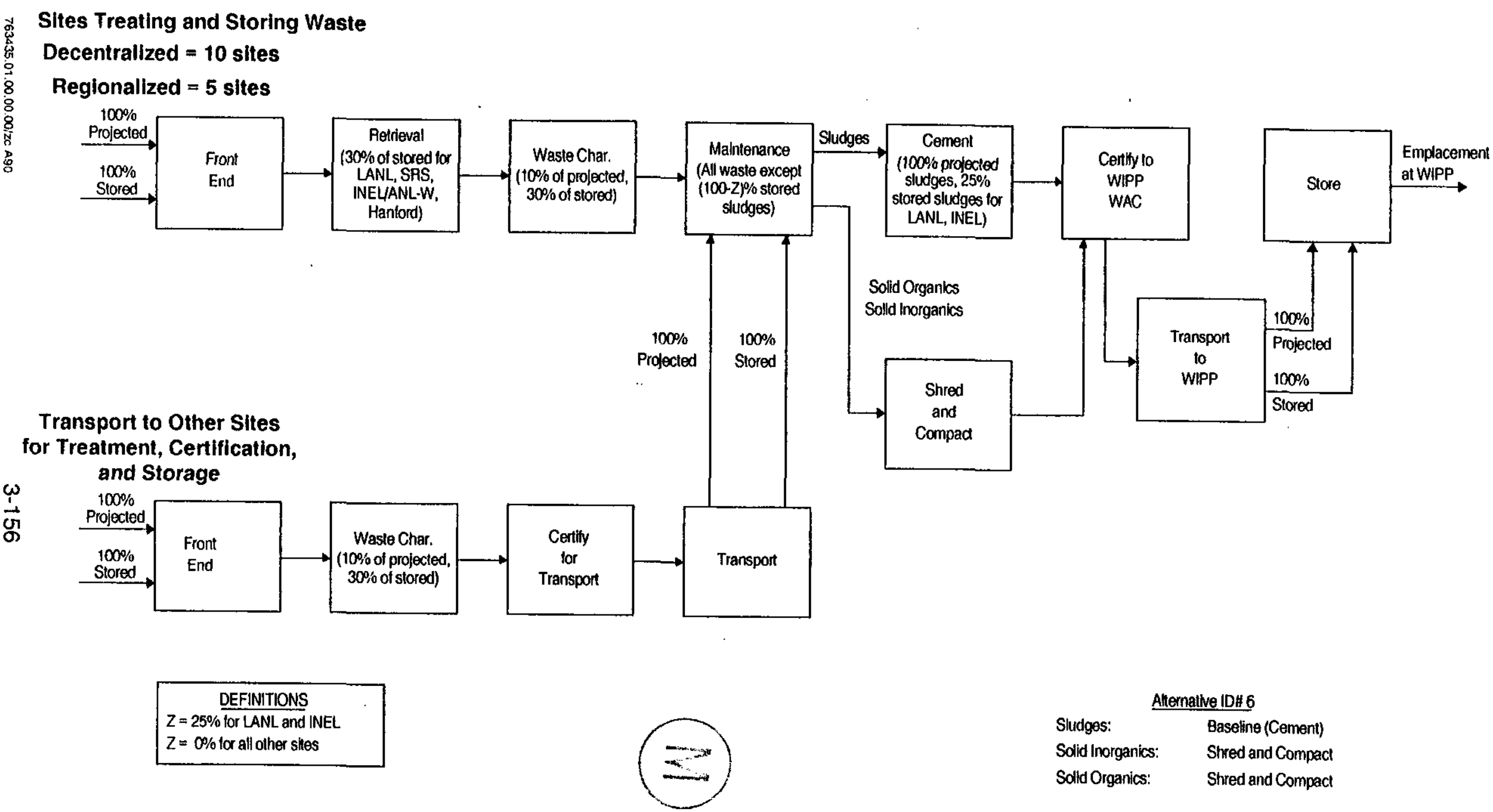
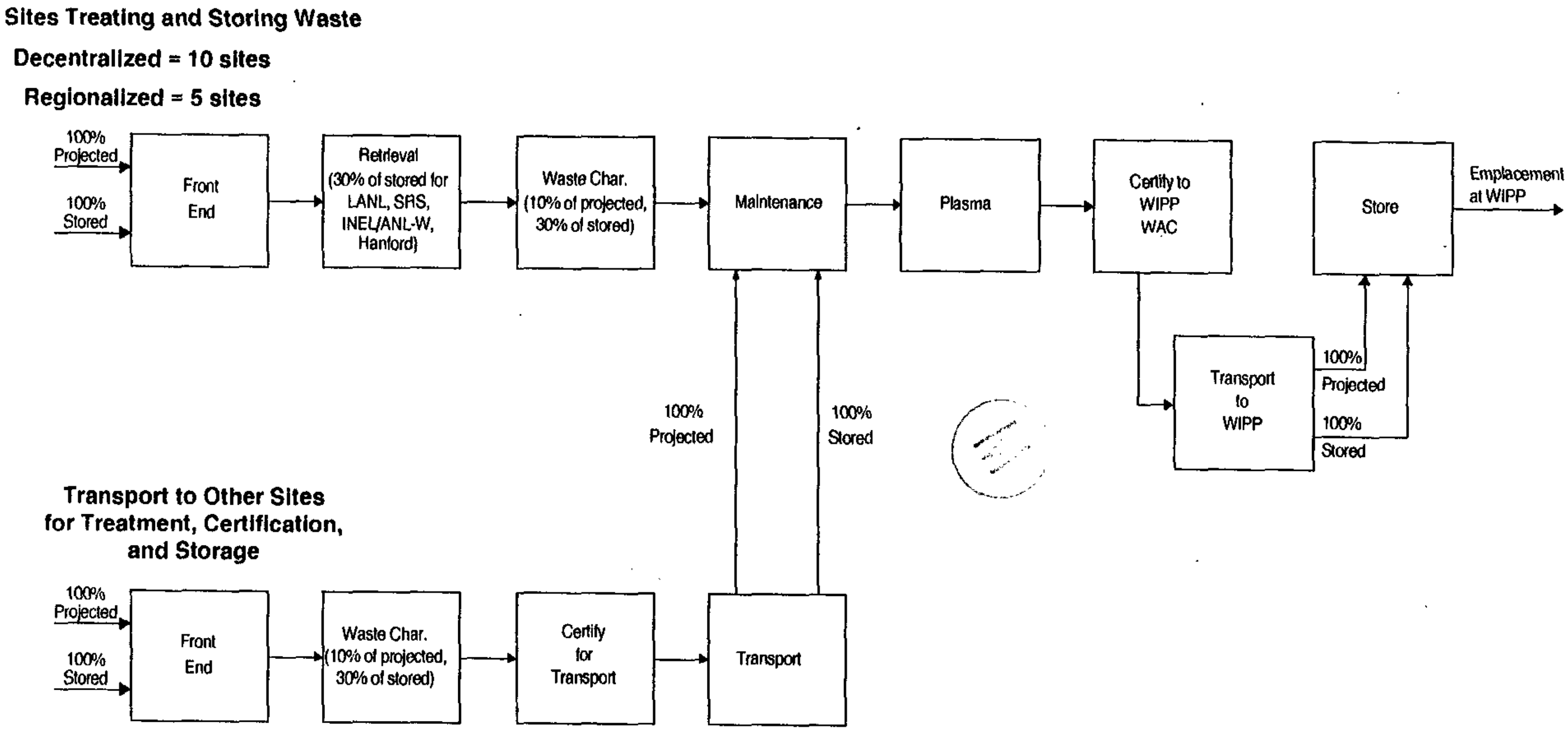


Figure 3-29

Decentralized and Regionalized Alternative ID# 6 Contact Handled Process Flow Diagram C

DOE/WIPP 95-2135 10/13/95

763435.01.00.00.00/zc A91

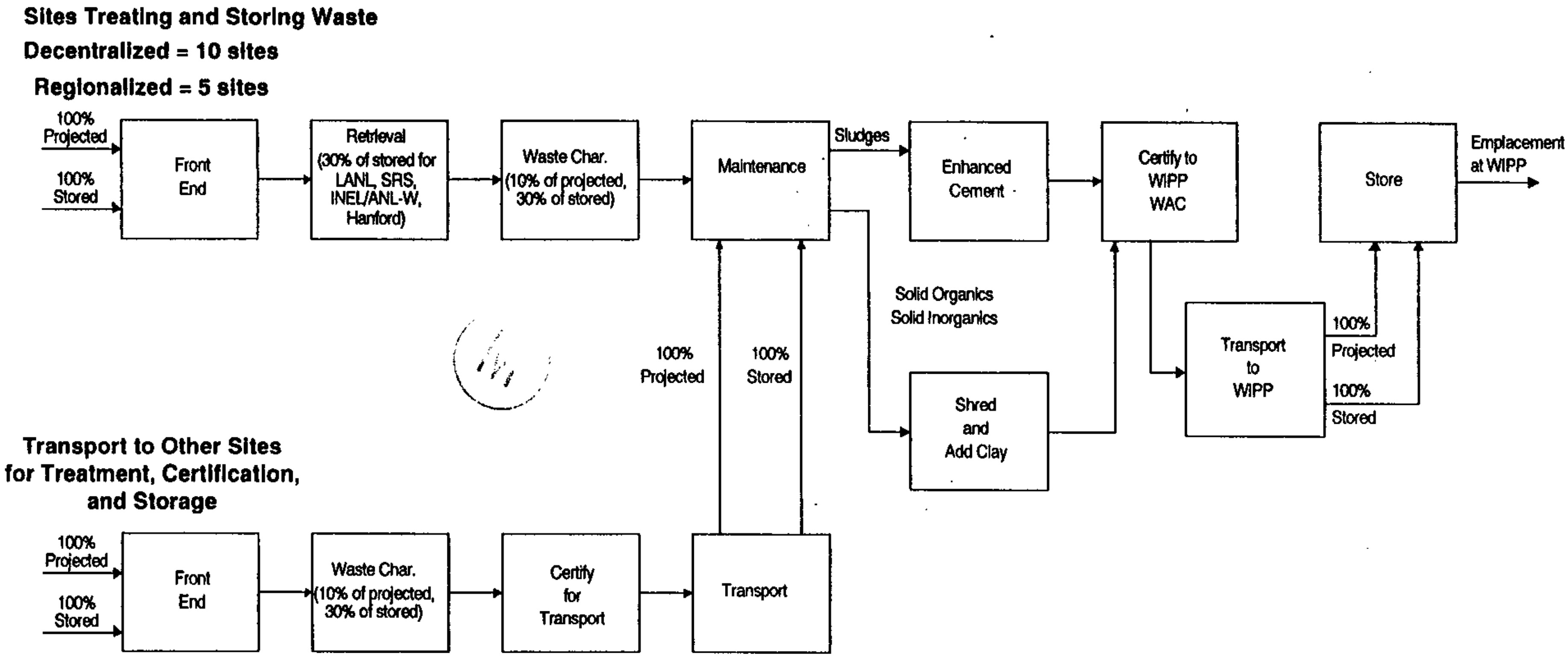


Alternative ID# 10	
Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure 3-30

Decentralized and Regionalized Alternative ID# 10 Contact Handled Process Flow Diagram D

783435.01.00.00/zc A92



Alternative ID# 94(a-f)	
Sludges:	Enhanced Cement
Solid Inorganics:	Shred and Add Clay
Solid Organics:	Shred and Add Clay

Figure 3-31

Decentralized and Regionalized Alternative ID# 94(a-f) Contact Handled Process Fl[illegible] Diagram E

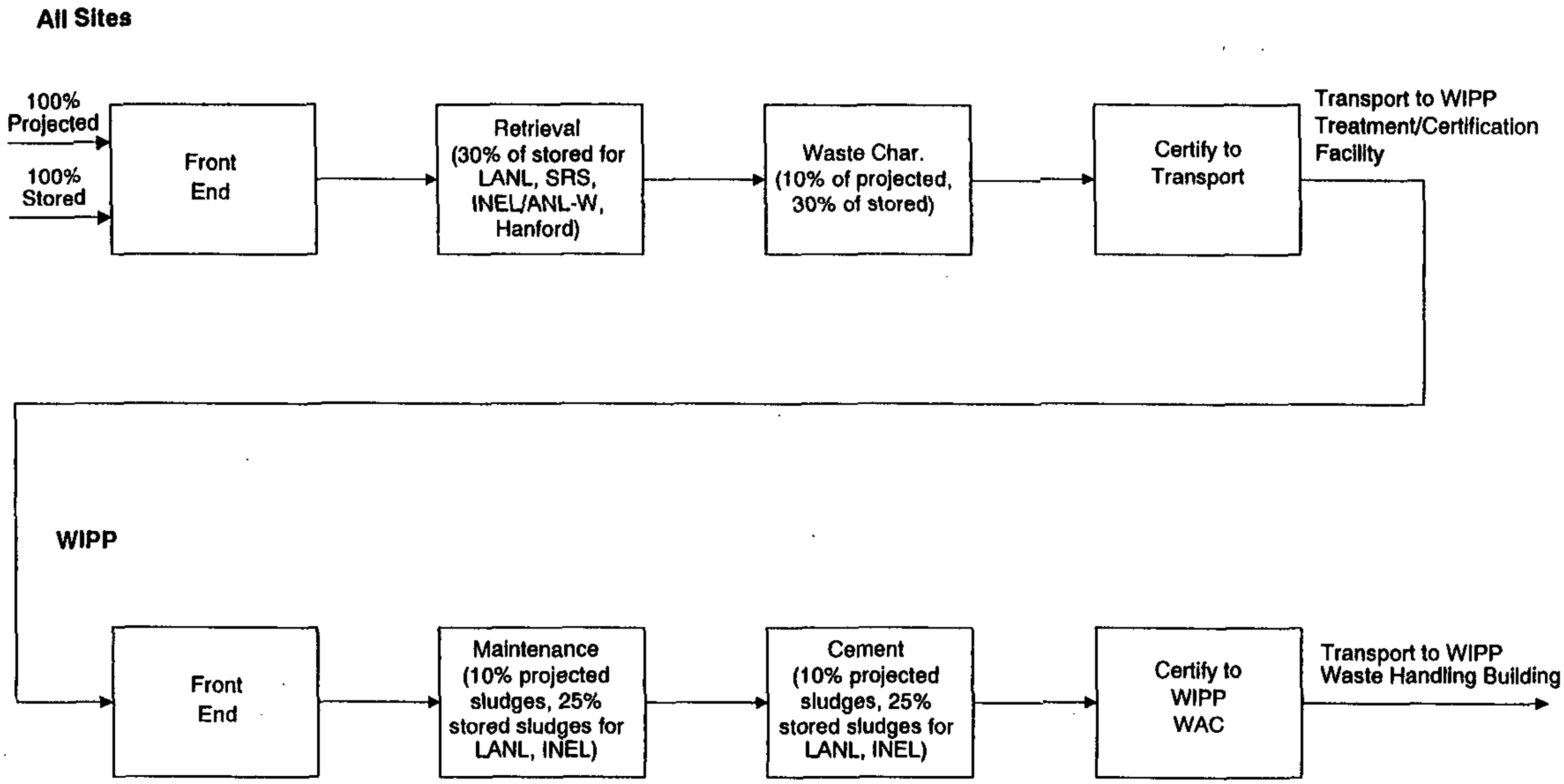
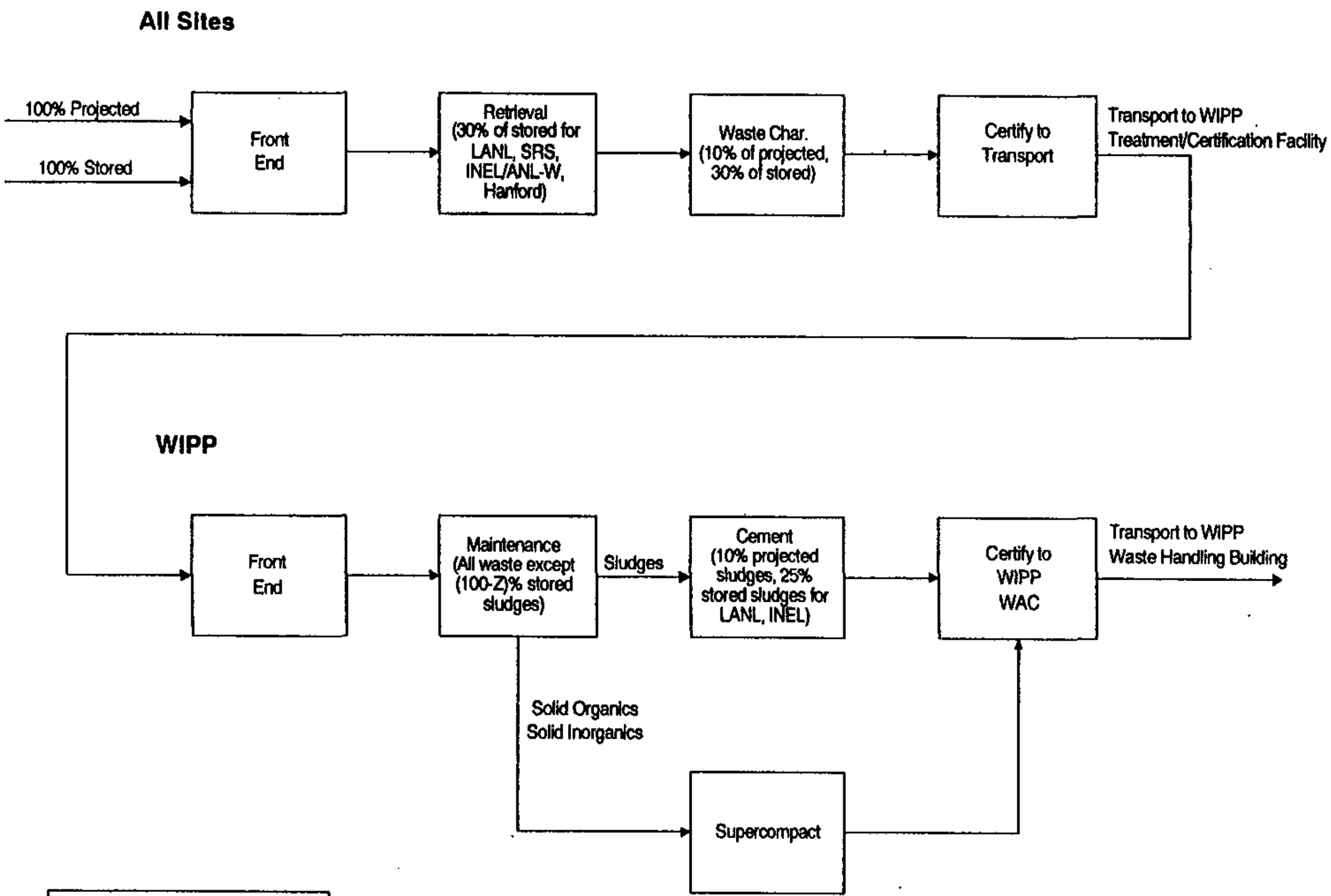


Figure 3-32

Centralized Base Case and Alternative ID #s 33, 35(a&b), 83, and 111 Contact Handled Process Flow Diagram F

763435.01.00.00.00/zc A94



DEFINITIONS
Z = 25% for LANL and INEL
Z = 0% for all other sites

Alternative ID# 1

Sludges:	Baseline (Cement)
Solid Inorganics:	Supercompact
Solid Organics:	Supercompact

Figure 3-33
Centralized Alternative ID#s 1 and 77(a-d) Contact Handled Process Flow Diagram G

763435.01.00.00.00/zz A95

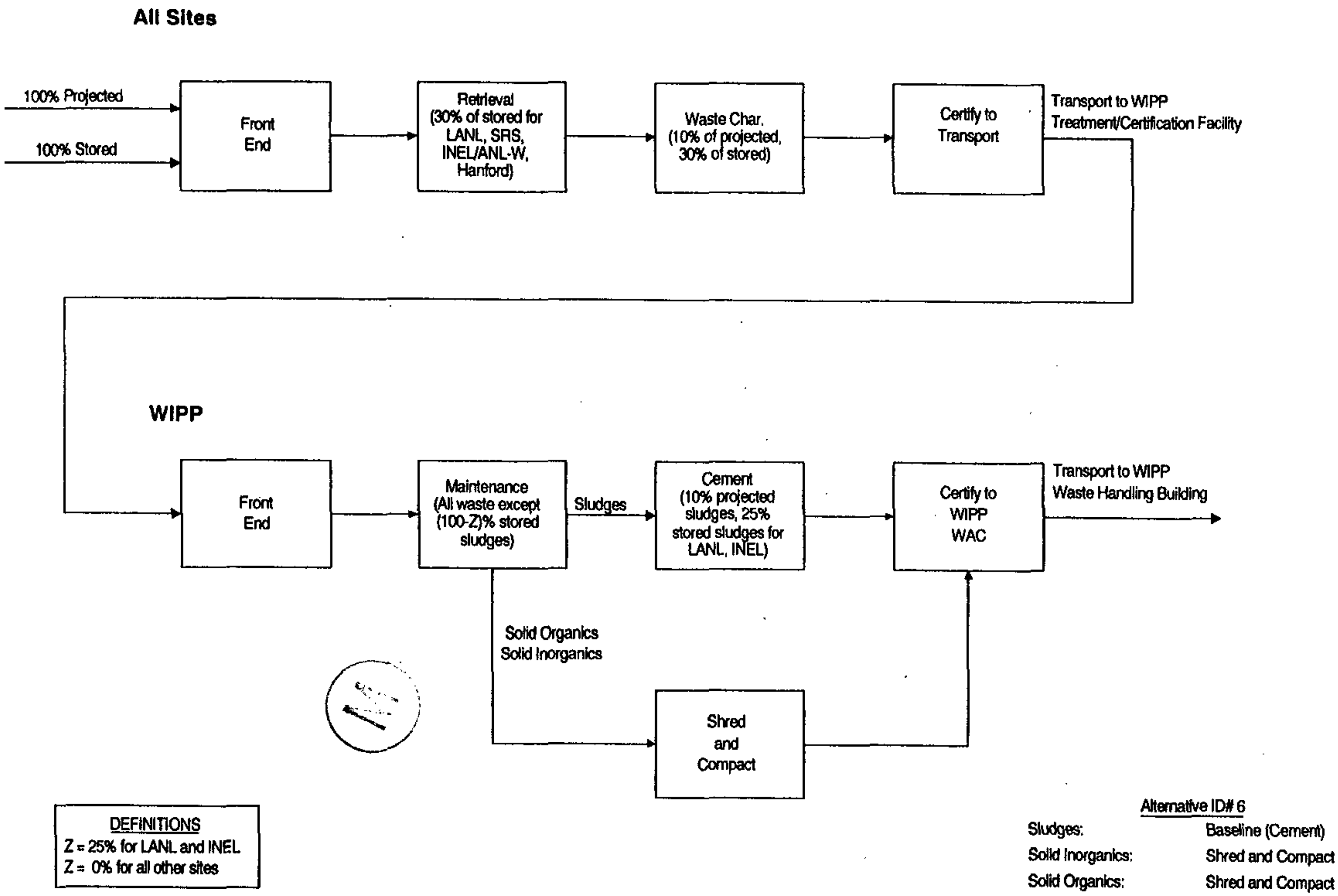
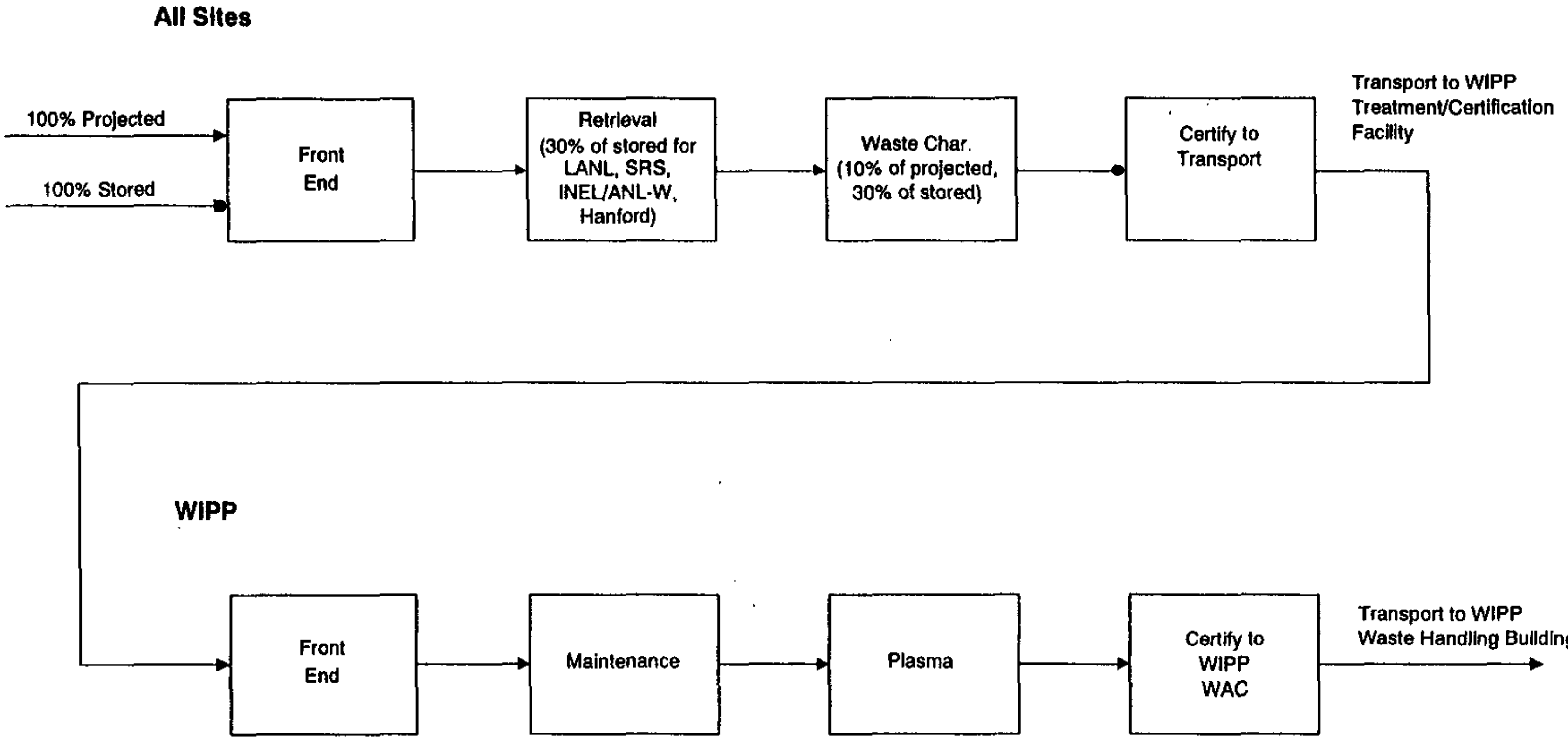


Figure 3-34

Centralized Alternative ID# 6 Contact Handled Process Flow Diagram H

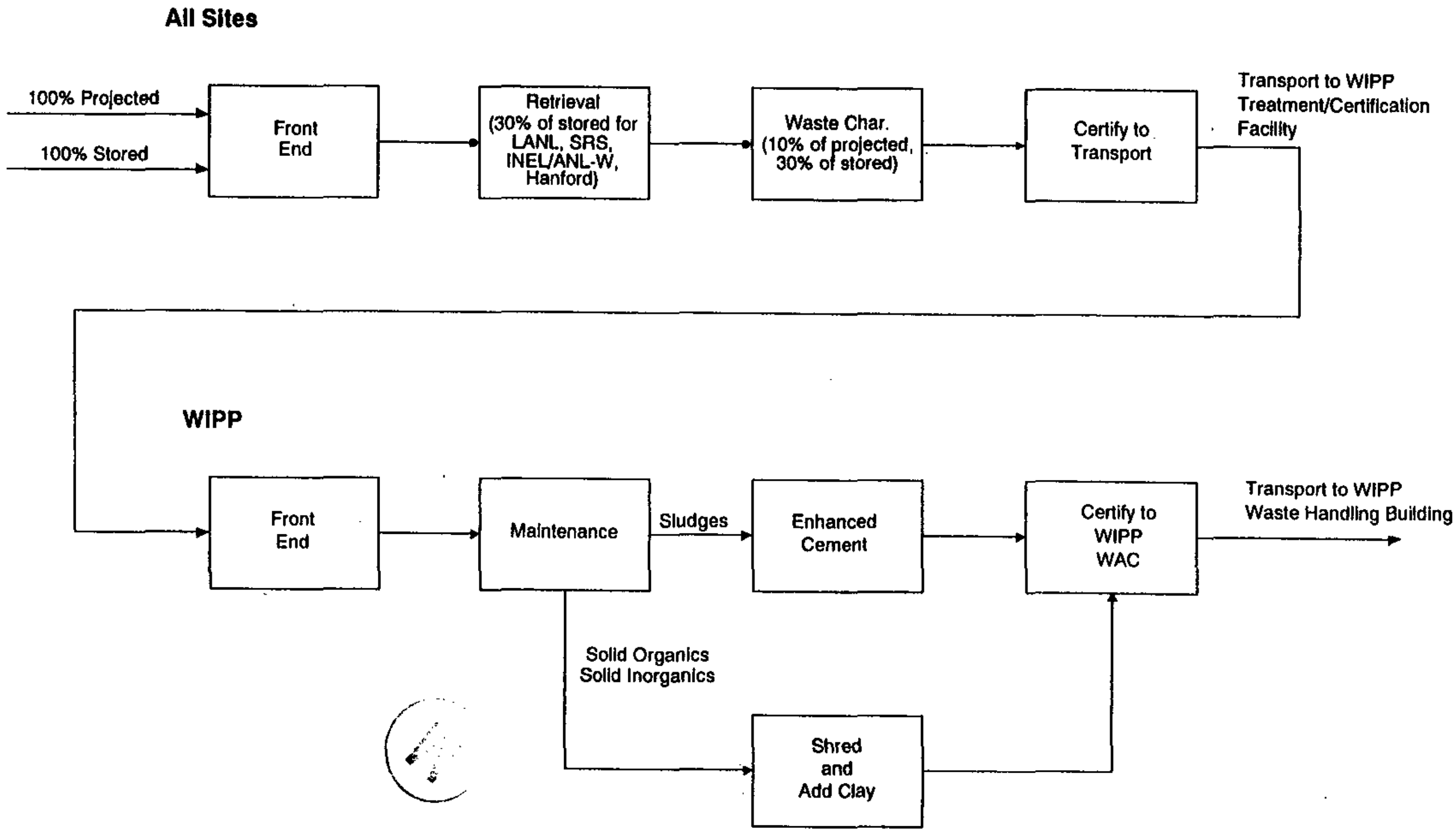


<u>Alternative ID# 10</u>

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure 3-35

Centralized Alternative ID# 10 Contact Handled Process Fl~~y Diagram I



Alternative ID# 94(a-f)

Sludges:	Enhanced Cement
Solid Inorganics:	Shred and Add Clay
Solid Organics:	Shred and Add Clay

Figure 3-36
Centralized Alternative ID# 94(a-f)
Process Flow Diagram J

783435.01.00.00.00/zz A97

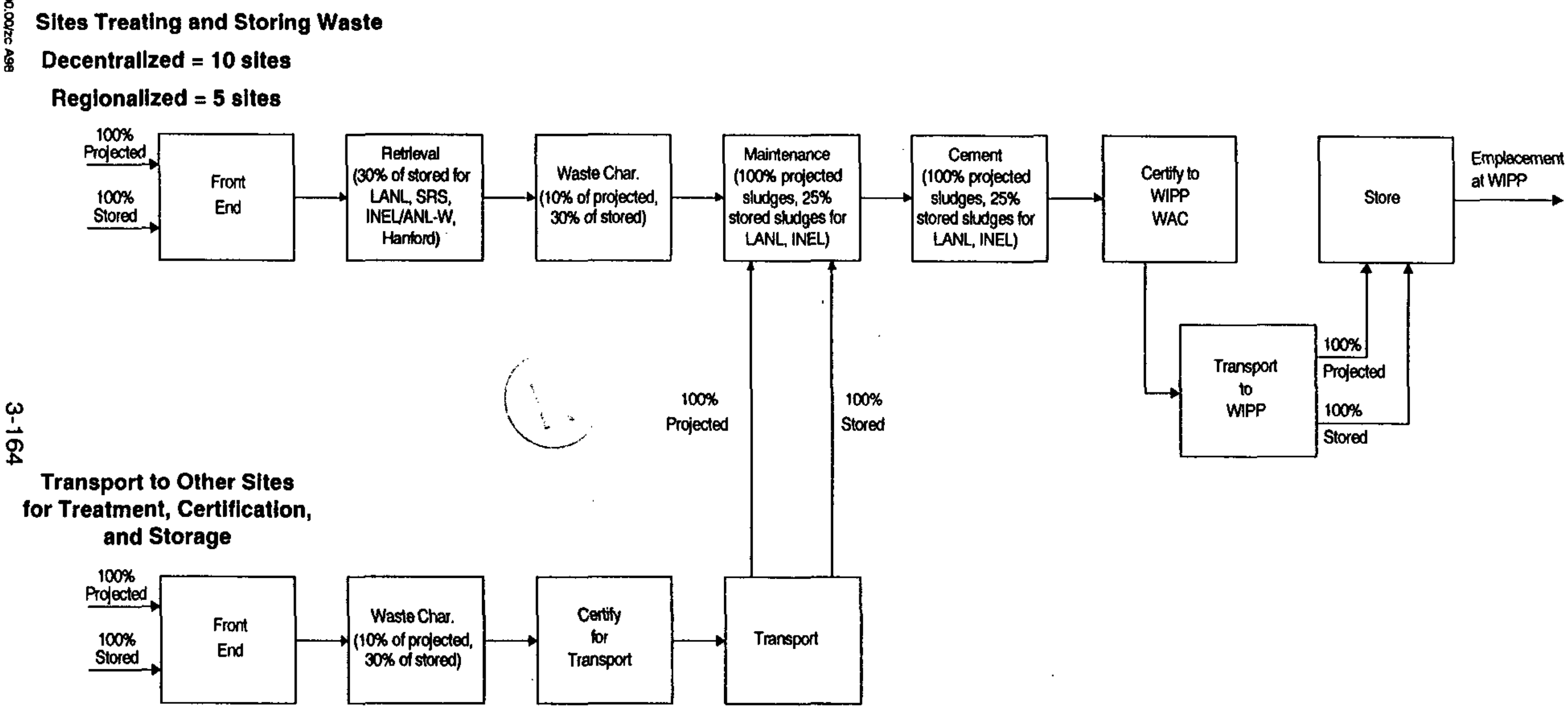


Figure 3-37

Decentralized Base Case Remote Handled Process Flow Diagram K

compacting, plasma melting, enhanced-cement processing, and shredding and adding clay.

- Storage: This module consists of a RCRA-compliant storage building sized to accommodate an accumulation of up to 20 years' volume of waste input from treatment modules. Storage area features include spill collection, sloping floors, sumps, and concrete berms. Monitoring is included for both gamma and alpha radiation control.

- Certification: Certification consists of storage of incoming material, assay and certification, and truck loading. The facility is equipped with a bridge crane and a forklift. It is assumed that certification operations will take place indoors.

- Transportation: Transportation consists of truck shipments. Equipment includes a tractor and trailer transporting three TRUPACT-IIs for CH waste or one RH cask (RH-72B) (a cylinder consisting of a separate inner canister within an outer cask protected by impact limiters at each end) for RH waste.

The process flow diagrams are developed from multiple data sources, and TRU waste processing knowledge from various sources; therefore, the uncertainty of the process flow diagrams cannot be quantified, but should be in the same order of magnitude as the documents used as guidelines for this study. The process flow diagrams developed for this study were designed mostly in accordance with the EM-PEIS and the WMFCITRUW report, however, not every module recommended in the WMFCITRUW report was included in this study. The reasons for deviating from the recommended WMFCITRUW guidance include 1) minimizing the costs of duplicate equipment contained in more than one module, and 2) more accurately representing the functions in existing and planned TRU waste facilities.

Mass and volume throughput are calculated using data from the WIPP BIR (DOE, 1995e). These rates are calculated using a 20-year processing period and a 4,032-hour working year. The mass or volume input to each of the individual modules is shown in Appendix O and is used as the basis for the module throughput which is the primary data used to estimate the cost of the module.

"The TRU waste disposal inventory in the BIR is derived from existing information on waste, which has been provided by DOE TRU waste generator/storage sites and is predominately based on process knowledge" (DOE, 1995e). Any uncertainty within the BIR is carried into this EA study. Calculated processing rates using a 20-year period and 4,032-hour working year may also introduce a level of uncertainty in estimating the costs. Many of the calculated processing rates were below or beyond the range of processing rates listed in the WMFCITRUW report and may cause the calculated costs to be skewed.

Numerical data values for cost versus flow rate information were obtained from the authors of the WMFCITRUW and used to construct approximate relations or curve fits for cost versus mass or volume throughput for a specific processing module. Cost data are available in the WMFCITRUW report according to specific project activities including pre-operations (pre-ops), planning life cycle cost (PLCC), construction, O&M, and D&D. Appendix P provides additional information on the method for establishing the modules. The PLCC is the summation of pre-ops, construction, O&M and D&D cost.

The WMFCITRUW was developed specifically to calculate facility costs in the EM-PEIS. Neither the WMFCITRUW nor the EM-PEIS provide a quantitative uncertainty of the costing data. From the costing categories listed in Plant Design and Economics for Chemical Engineers (Peters et al., 1991), the WMFCITRUW study cost estimates fall into the Study Estimate cost category where the probable accuracy of the estimate is plus or minus 30 percent.

To ensure that the waste processing cost estimates presented in this study account for those facilities that currently exist, a list of existing facilities was assembled from information gathered from several sources, including personal communications (Bjotued, 1995; George, 1995) and preliminary information being developed by the DOE National TRU Program Office (NTPO). Data from these sources were consolidated into a single list used to describe existing TRU waste processing facilities for this study, as shown in Table 3-47. All of the information sources have not been subject to extensive review, thus uncertainty of the data arises from the uncertainties associated with the sources themselves, and any changes that have occurred between the current time and the time these sources were compiled.

The existing facility list was used to adjust process cost estimates. O&M and D&D costs were added and applied to facilities that had current existing TRU waste processing facilities for a specific module, while the PLCC was applied to facilities that did not have existing processing capabilities for a specific module.

Combining all of the information gathered, computer cost-model programs have been developed using Visual Basic computer programming language and cost equations were applied based on a calculated mass or volume throughput for a specific module. These programs were implemented using a computer spreadsheet with mass and volume throughput data. The computer cost model programs calculate the cost for each processing module for each alternative in each configuration. Summary results for process costs are presented in Section 3.7.4.1 of this report.

3.7.2.2 TRU Waste Transportation Cost Estimation Methodology

This section presents the information sources and assumptions used to complete transportation cost estimations for the various alternatives.

The guidance chosen for development of transportation cost estimates comes from "Waste Management Facilities Cost Information for Transportation of Radioactive and Hazardous Materials," (Feizollahi et al., 1994). This report was also used as guidance for development of transportation cost estimation in the Draft EM-PEIS. The report also covers the procedure for estimating the costs of various types of wastes, including an entire section on RH and CH TRU waste transportation. The report includes only guidance for estimating the cost of transportation of waste; loading and unloading operations are included in the facility operating and maintenance costs.

It is assumed that all CH TRU waste will be shipped by truck in TRUPACT-II containers, which have mass, volume, and radionuclide restrictions that limit the amount of waste transported in one shipment. Using volume and mass data for waste at each of the sites, both mass-limited and volume-limited cases were developed (Appendix P), but radionuclide content was not considered a limiting factor for CH-TRU waste. For RH-TRU waste, however, radionuclide limitations were important, and the volumes had to be further reduced to meet container and shipping

TABLE 3-45

EXISTING TRU FACILITIES

		Waste Processing Functions							
							Treatment[b]		
Site	Retrieve	Waste Char	Front End	Certify/ Ship	Maint	Storage	Grout	Super Cmpct	Plasma
Major Generator/Storage Sites									
ANL-E	–		X		X	X			
Hanf		X	X	X	X	X			
INEL/ ANL-W		X	X	X	X	X			X[c]
LANL		X	X		X	X	X		
LLNL	–	X	X	X	X	X			
Mound	–		X		X				
NTS	–		X		X	X			
ORNL	–	X	X	X	X	X			
RFETS	–	X	X	X	X	X	X	X	
SRS			X		X	X			
Small Quantity Sites									
Ames	–	P	[a]	P	–	–	–	–	–
BCLDP	–	P	[a]	P	–	–	–	–	–
BT	–	P	[a]	P	–	–	–	–	–
ETEC	–	P	[a]	P	–	–	–	–	–
KAPL	–	P	[a]	P	–	–	–	–	–
LBL	–	P	[a]	P	–	–	–	–	–
Pad	–	P	[a]	P	–	–	–	–	–
Pantex	–	P	[a]	P	–	–	–	–	–
SNL	–	P	[a]	P	–	–	–	–	–
U Mo	–	P	[a]	P	–	–	–	–	–
WVDP	–	P	[a]	P	–	–	–	–	–

Notes:
X = Site has existing facilities to perform this function. No credit was given for planned facilities. Costs only include 20 years of O&M and D&D.
– = Site will not require this function.
P = This function will be accomplished utilizing portable equipment.
[a]For sites which will use portable equipment for waste characterization and certification and shipment, it is assumed that existing facilities will be sufficient for administrative purposes.
[b]No facilities exist to treat TRU waste using shred/compact, shred/add clay, or enhanced cement.
[c]It is assumed that the INEL Pit 9 treatment facility will be available to treat stored waste.

specifications. Appendix P shows how the number of shipments was derived for each EA and each configuration. The number is drums allowable in a TRUPACT II shipment is dependent on the density of the waste. Shipments may include as many as 42 drums of low density waste or as little as 14 drums of high density waste. It should be noted that the number of shipments used to calculate transportation costs differs from the number of shipments used to estimate transportation risks. Transportation risk methodology (Section 3.5.2) adjusts the number of shipments so that they represent a conservative bounding case. Transportation costs were based on less conservative estimates as shown in Appendix P.

The planned route and total mileage traveled for each of the shipments was determined by the HIGHWAY 3.3 Routing Model. The model is an extensive computerized atlas that determines the optimum route for a given origin and destination. The DOE sites that produce and treat TRU waste are all included, as is the WIPP repository. The program allows the user to place constraints on route choices, and several were invoked in order to choose the most preferred route for TRU waste transportation. Route constraints include the barred use of roads that prohibit truck use, the preferred use of routes already designated for hazardous waste transportation, and the use of roads in New Mexico designated as preferred shipment routes to the WIPP. The model is described in Section 3.5.2, Methodology Used to Evaluate Factor 5 (Risk of Transportation).

There are three types of costs associated with transportation. Carrier costs and hardware costs are functions of a moving vehicle and are combined to make up the "costs per loaded mile" (CPLM). Carrier costs include tractor, fuel, labor, insurance, security escort, taxes, tools, permit fees, and related costs incurred during waste transportation. Hardware costs are associated with maintenance of the specialized trailers and railroad cars used to transport waste. Fixed costs are independent of the distance traveled and considered separately. Fixed costs include demurrage costs of the carrier and the hardware used in the shipment. The total cost for a single shipment can be determined by adding the fixed costs to the product of the CPLM and the number of miles traveled. It should be noted that the CPLM unit rate is based on one-way mileage from origin to destination, but that the total cost for one shipment includes the return trip (see Section 3.5.3.5).

Finally, the process of estimating the costs is a straightforward analysis (Appendix P). The costs are derived from the number of shipments, taking into consideration the volume of drums or standard waste boxes, waste density, and the radionuclide inventory of the waste. The number of shipments are applied to the CPLM and the round-trip mileage, and the fixed costs are added to determine the total transportation costs for each individual site. Transportation cost estimations were performed for the decentralized and regionalized cases and each alternative therein. An estimation was also made for the centralized baseline. Since the centralized transportation configuration requires that all waste be treated at the WIPP, all the centralized alternatives are similar from a transportation point of view. Results are discussed in Section 3.7.4.2.

There are relatively few sources of uncertainty in the development of the transportation cost estimations. Included in these are the uncertainty of the waste inventory requiring transportation and the uncertainty in the numbers provided in the report used as guidance for estimate development. The level of uncertainty is discussed in Section 3.7.4.2.

3.7.2.3 Backfill Emplacement Cost Estimation Methodology

Backfill emplacement costs were developed by analyzing a logical approach to emplacing material into a panel. The approach was generic in nature to accommodate the fact that an exact method of emplacement has not been developed. The approach for estimating the costs of emplacement are generated by applying mine development data sources to an activity that is not characteristic to the mining industry (Appendix P). The backfilling of waste emplaced in a mine has not been an activity that is common practice for the DOE or mining industry.

The cost estimation of a backfill operation had to be developed based on the rate at which backfill would be emplaced. The assumptions for this estimation are listed in section 3.7.3. Once the capacity of the equipment requirement is determined a cost model determines the cost requirement for backfill.

The primary source of costing information is the SME Mining Engineering Handbook (Hartman, 1992) which provides a logical approach to the activities that would be performed. Assumptions had to be made in order to provide some logical data points for performing a backfill activity. An estimation of this type would be categorized as a Study Estimate where the uncertainty of the estimate is plus or minus 30 percent.

Data for the estimate is dependent on the mass and volume of backfill material. The backfill is emplaced daily as a batch and would not interrupt the waste emplacement activities. The working rate for backfill emplacement is assumed to be 960 hours per year for 35 years.

Calculation of the cost estimation is developed utilizing a spreadsheet format that applied the cost equations to the rate at which the backfill would be emplaced. The spreadsheet calculated the cost for each alternative that had a backfill associated with it.

3.7.2.4 WIPP Waste Operations Emplacement Cost Estimation Methodology

The cost estimation for the impacts associated with the WIPP operations only analyzed the incremental costs to the actual activities associated with waste handling and emplacement. These impacts provide a measure of the planning necessary to implementing an alternative.

For each of the alternatives and configuration (decentralized, regionalized, centralized) the throughput of the waste is determined in order to handle and emplace the waste at WIPP. The throughput rate is based on the number of transported waste shipments to be handled at WIPP (see Appendix P). The waste work-off and repository configuration is analyzed against the baseline to determine additional equipment requirements or modifications. The next parameter is to determine the manpower necessary to handle the waste was also determined. Guidance was provided in order to determine the size of a crew and the waste handling capacity.

The number of waste shipments to the WIPP is determined based on the methodology for transportation (see section 3.7.2.2). The throughput rate is calculated by applying the number of shipments to the operational period of the WIPP. The manpower requirements for the waste handling operations are given as three possible crews based on the throughput rate. The capital equipment requirement is estimated and totaled for the applicable alternative.

Calculation of the WIPP handling cost estimation was developed utilizing a spreadsheet format that applied the capital requirements and the throughput rate of the waste to the manpower requirement. The cost was calculated for each alternative and case. A comparative analysis was performed to the baseline decentralized alternative.

3.7.2.5 Schedule Methodology

The EA analysis included developing a permitting, construction, and operating schedule for each alternative and the baseline. Schedules are developed for each treatment option and then combined as appropriate to determine a schedule for each alternative. For example, the schedule for Alternative 94 incorporates the schedules for treatment scenarios of Enhanced Cement and Shred and Add Clay. The schedules will not be affected by the different site configurations, so these are not included.

For each treatment option, several steps are followed in order to arrive at a schedule. It was assumed that these treatment units would be capital projects, so a generic "Capital Project Logic Flow Diagram," developed for RFETS capital projects, was modeled to determine the major activities and their logical relationship to the other major activities (Appendix Q). To arrive at meaningful time estimates, it was necessary to develop some schedule detail, which was based on previous experience at RFETS, INEL, and Hanford. For some of the tasks, a deterministic approach was used, also referred to as Critical Path Method (CPM) scheduling, based on similar or identical work performed previously. For other tasks, a Program Evaluation and Review Techniques (PERT) analysis was applied to arrive at a probable duration estimate. PERT uses three time estimates for each activity: an optimistic or minimum time T_o, a most likely or modal time T_m, and a pessimistic or maximum time T_p. This probabilistic approach lends itself well to activities for which there is little historical record. PERT analysis was applied to the Plasma alternative, whereas a CPM analysis was applied to the Shred and Compact alternative. Once the task durations were determined, the activities were loaded into PRIMAVERA with the appropriate logic ties, and the system was allowed to perform the schedule calculations. Table 3-46 presents the results of a PERT analysis that was used as a starting point for estimating activity durations for several of the major activities.

The operational life for the WIPP site was constrained to be 35 years. This provides the basis for the operational and backfill activities to be performed within the limitation of time. Therefore, the backfill and waste emplacement operations do not have any significant schedule impact.

Schedule scenarios for each treatment option are developed relative to the baseline and Shred and Compact to have a reference point for subsequent schedule development. The primary differences between the schedules for each treatment option are the durations estimated for the design, construction, and D&D activities. The more complex the treatment process, the longer the durations for each of these activities. The baseline and Shred and Compact scenarios are assumed to have the shortest schedules because they employ the simplest technologies, followed in order of complexity by Shred and Compact, Enhanced Cement, Supercompact, and Plasma. For the Plasma Melter scenario, the RCRA permitting and National Environmental Policy Act (NEPA) documentation durations are also increased because of the likelihood of significant public and agency comments.

1 **TABLE 3-46**

PERT ANALYSIS TIME ESTIMATES

Major Activities[a]	To	Tm	Tp	Te	Te in Days
Preliminary Safety Analysis	.890	1.000	2.250	1.190	298
Final Safety Analysis Report	1.420	2.000	4.440	2.310	578
Title I Design	.375	.500	1.250	.604	151
Title II Design	.738	.860	2.810	.998	250
Construction	1.910	2.000	3.160	2.178	545
NEPA	1.781	2.120	7.632	2.982	746
Prevention of Significant Deterioration Preparation	.840	1.000	2.250	1.182	295
Prevention of Significant Deterioration Approval	.335	.830	2.330	.998	249
NESHAPS	.750	1.000	2.500	1.208	302
Resource Conservation & Recovery Act Permit Preparation	.269	.320	.720	.378	95
Operations Readiness Review	1.840	1.840	4.287	2.248	562
Te=New Estimated Duration in Years	$Te=\frac{To+Tm(4)+TP}{6}$				

[a]Some major activities may be performed in parallel.
*Values are approximate.

3.7.3 Assumptions and Data for Factor 7

Two major sources of data are used for the analysis of cost and schedule:

- The initial retrievable and projected waste volumes are obtained from the WIPP BIR (DOE, 1995e) (see Appendix O).
- Guidance for process flow diagrams and costing and cost curves are obtained from the WMFCITRUW report.

The major assumptions follow:

- Mass and volume changes occur during certain processing activities. A summary of the mass and volume changes is presented in Table 3-47.
- The volume of waste categorized as "unknown" is processed the same as solid organics and inorganics. However, the mass of unknown waste is assumed to be zero because no information is available regarding the density of the unknown waste and the volume of this waste is small compared to the total volume of waste destined for WIPP.
- Thirty percent of the stored waste at Los Alamos National Laboratory (LANL), Savannah River Site (SRS), INEL/Argonne National Laboratory-West (ANL-W), and Hanford requires retrieval.
- Twenty-five percent of stored sludges at LANL and INEL requires re-grouting, and all of the stored sludges at ORNL require grouting.
- Waste is treated and or stored according to the site configurations denoted in Table 3-48.
- Waste is processed 4,032 hours per year over a 20-year waste processing facility operating life.
- All waste within a major waste form category (i.e., sludges, solid organic, solid inorganic) can be treated using a specified technology.
- The supercompaction module does not include shredding.
- Costs for a vitrification unit are considered adequate for the costs for a plasma melter.
- Costs for enhanced cement processing are identical to costs for grouting except for material costs.
- Costs for shredding and adding clay are identical to costs for grouting except for material costs.

1 **TABLE 3-47**

MASS AND VOLUME CHANGES FOR WASTE TREATMENT/PROCESSING MODULES

Module	Mass Ratio (Output/Input)	Volume Ratio (Output/Input)
Front End	1.0[a]	1.0[b]
Retrieval	1.1[a]	1.1[b]
Waste Characterization	1.0[b]	1.0[b]
Maintenance	1.0[b]	1.1[b]
Grout	3.15[a]	2.5[b]
Supercompact	1.1[a]	0.35[b]
Shred and Compact	1.1[a]	0.76[b]
Shred and Add Clay	2.35[b]	1.0[b]
Plasma	1.0[a]	0.33[b]
Certification	1.0[b]	1.0[b]
Storage	1.0[b]	1.0[b]

[a]Source (Feizollahi and Shropshire, 1994)
[b]Values derived from engineered calculations.

TABLE 3-48

SITE TRANSFERS FOR THE DECENTRALIZED, REGIONALIZED, AND CENTRALIZED CONFIGURATIONS

Decentralized			Regionalized			Centralized		
Site	**CH**	**RH**	**Site**	**CH**	**RH**	**Site**	**CH**	**RH**
ANL-E*	WIPP	ORNL+	ANL-E	SRS	ORNL	ANL-E	WIPP	WIPP
Ames	ANL-E#		Ames	SRS		Ames	WIPP	
BCLDP		ORNL+	BCLDP		ORNL	BCLDP		WIPP
BT	Mound	ORNL+	BT	SRS	ORNL	BT	WIPP	WIPP
ETEC	NTS		ETEC	INEL/ ANL-W		ETEC	WIPP	
INEL/ ANL-W*	WIPP	WIPP	INEL/ ANL-W*	WIPP	Hanford	INEL/ ANL-W	WIPP	WIPP
KAPL	Mound	ORNL+	KAPL	SRS	ORNL	KAPL	WIPP	WIPP
LANL*	WIPP	WIPP	LANL*	WIPP	Hanford	LANL	WIPP	WIPP
LBL	(LLNL)		LBL	Hanford		LBL	WIPP	
LLNL*	WIPP		LLNL	Hanford		LLNL	WIPP	
Mound*	WIPP		Mound	SRS		Mound	WIPP	
MU	ANL-E#		MU	SRS		MU	WIPP	
NTS*	WIPP	WIPP	NTS	INEL/ ANL-W	Hanford	NTS	WIPP	WIPP
ORNL*	WIPP	WIPP	ORNL* (rh)	SRS	WIPP	ORNL	WIPP	WIPP
PA	ORNL		PA	SRS		PA	WIPP	
Pantex	LANL		Pantex	LANL		Pantex	WIPP	
RFETS*	WIPP		RFETS*	WIPP		RFETS	WIPP	
Hanford*	WIPP	WIPP	Hanford*	WIPP	WIPP	Hanford	WIPP	WIPP
SNL/NM	LANL		SNL/NM	LANL		SNL/NM	WIPP	
SRS*	WIPP	WIPP	SRS*	WIPP	ORNL	SRS	WIPP	WIPP

Notes:

*	Denotes a processing site.
ORNL+	*Remote handled wastes from BCLDP, BT, KAPL, (these are not discussed in the EM-PEIS)* and ANL-E should be processed at ORNL instead of Mound because Mound currently does not process or store RH waste.
ANL-E#	The EM-PEIS discusses that ANL-E will process and ship their own CH waste, but does not cover Ames and MU, which are closer to ANL-E than ORNL.
(LLNL)	EM-PEIS indicates LBL waste will be shipped to Hanford. LBL waste should be shipped to LLNL because it is much closer.

- Costs for shredding and compacting are analyzed as a modified cost module for supercompaction.
- Funding is unconstrained for the purposes of developing schedules.
- Costs are in 1994 dollars and do not take into account escalation or the time value of dollars.
- The operations at WIPP are 35 years.
- The waste emplacement operations at WIPP consists of two eight hour shift operations five days a week.
- Both waste handling and backfill are completed in the 35 year operational period.
- Waste emplacement is dependent upon the number of TRUPACT-IIs per day.
- Backfill costs are based on a batch per day (tons) of material that would be emplaced each day.
- Backfill of the rooms does not impact operations.

3.7.4 Results of Analysis for Factor 7

3.7.4.1 Process Costing Results

As described in Section 3.7.2.1, process costs are calculated using computer program cost models developed for this study (Appendix P). Costs are calculated for each alternative in each configuration for CH waste and for decentralized baseline for RH waste. Cost values are based on 1994 cost data and do not take into consideration time value of money or escalation for expenditures occurring during the planning life cycle (Feizollahi and Shropshire, 1994). Summaries of these costs are presented in Tables 3-49 and 3-50. These tables present the summary of process costs for the baseline and each of the different alternatives in each of the configurations for CH waste and for the decentralized baseline for RH waste. Processing schemes for Alternatives 33, 35(a&b), 83, and 111 are identical to the processing schemes for the baseline for each of the configurations, therefore their processing costs are assumed to be identical to the processing costs for the baseline. The processing scheme for Alternative 77 (a-d) is the same as the processing scheme for Alternative 1 for each of the configurations; therefore, its processing costs are identical to the process costs for Alternative 1. Alternative 33, 35(a-b), 77(a-d), 83, and 111 will be omitted from further discussion in this section because they are not unique with respect to processing cost.

The range of processing costs for CH waste varies between $3.2 billion for the centralized baseline and $6.3 billion for decentralized Alternatives 94(a-f). The process costs for the decentralized alternatives are the highest for a specific alternative; the process costs for the centralized configuration are the lowest. This was expected due to process costs for treatment

1 **TABLE 3-49**

CH WASTE PROCESSING COST GRAND TOTALS
($K)

Alternative ID #	Decentralized	Regionalized	Centralized
Baseline	3,576,954	3,418,650	3,202,376
1	4,379,357	3,974.696	3,411,991
6	4,117,678	3,757,294	3,329,333
10	5,966,427	4,992,885	3,960,139
33	3,576,954	3,418,650	3,202,376
35 (a&b)	3,576,954	3,418,650	3,202,376
77(a-d)	4,379,357	3,974,696	3,411,991
83	3,576,954	3,418,650	3,202,376
94 (a-f)	6,301,672	5,502,932	4,217,091
111	3,576,954	3,418,650	3,202,376

1 **TABLE 3-50**

RH CENTRALIZED BASELINE COST PER SITE
($K)

Site	Cost
BCLDP	0
BT	0
HANFORD	173,279
INEL/ANL-W	170,849
KAPL	0
LANL	206,932
ORNL	339,190
SRS	121,730
GRAND TOTAL	1,011,980

(maintenance and specific alternative treatments) being applied to a larger number of sites in the decentralized (10 sites) and regionalized (5 sites) configuration as compared to the centralized (1 site) configuration.

The processing costs for the baseline are least expensive when compared to the alternatives; processing costs for Alternative 94 are most expensive. This results from a combination of effects. One explanation for this is that the treatment module throughput values for the baseline are lowest; treatment module throughput values for Alternative 94 (a-f) are highest. The baseline consists of treating to the WIPP-WAC (DOE, 1991c). Treatment to WAC entailed shredding and grouting a portion of the existing sludges and all of the projected sludges, along with repackaging waste as necessary to meet transportation and WIPP requirements. In Alternative 94(a-f) all of the waste is treated in some way by either repackaging, enhanced-cement processing, or shredding and adding clay. Thus, the "waste treatment" processing throughput for Alternative 94 (a-f) is higher than the baseline.

The second explanation is that for the shred-and-add-clay and, enhanced-cement cost modules, it is assumed that there are currently no facilities that had these processing capabilities. The result is that the PLCC is applied to all appropriate sites (decentralized, regionalized and centralized configurations) making Alternative 94 (a-f) more costly than other alternatives (e.g Alternative 1, etc.) where some facilities currently do have a specific processing capability.

Another observation from the information presented in Table 3-49 is that after taking the level of uncertainty of the cost estimations plus or minus 30 percent (Section 3.7.2.1), that the centralized alternative processing costs are approximately the same as compared to the decentralized baseline. The decentralized baseline represents the current strategy for managing CH waste.

The RH process costs for the baseline decentralized configuration is $1.0 billion.

3.7.4.2 TRU Waste Transportation Cost Estimation Results

This section provides information on the results of the transportation cost estimations for the various alternatives. For information regarding the sources and assumptions used to complete transportation cost estimations, refer to Section 3.7.2.2 and Appendix P.

Transportation cost estimations are performed for each configuration and alternative. Within the centralized, regionalized, and decentralized configurations, some of the alternatives are identical from a transportation standpoint, making the transportation costs for these alternatives the same. For example, the centralized configuration provides only one set of transportation requirements because all treatment occurs at the WIPP, making the transportation costs for all centralized alternatives the same. Similarly, the regionalized and decentralized alternatives that vary backfill options do not provide unique situations to transportation, so these cases have transportation costs equal to those of other alternatives. Alternatives that present transportation with a unique scheme include the baseline and Alternatives 1, 6, 10, and 94(a-f).

Shipments being limited by both mass and volume has a significant effect on the transportation costs for alternatives that result in a more dense waste form, especially supercompaction (alternatives 1 and 77), plasma melting (alternative 10), and shred/add clay (alternatives 94 a-f). In the case of supercompaction and plasma melting, the final waste volumes were significantly reduced, but the transportation costs for the decentralized configurations only reduced by less than 1 percent and less than 13 percent, respectively. In the case of alternative 94, the final waste volume was not decreased and the waste density was significantly increased, causing many of the shipments to become mass-limited. In the decentralized configuration, this had the effect of increasing the transportation costs by more than 66 percent. It is clear increasing waste density plays a key role in reducing the benefits derived from waste treatments that result in a volume reduction.

The transportation costs range from a minimum of $603.4 million for decentralized Alternative 10, which has the largest degree of waste volume reduction at the most number of sites, to a maximum of $1.2 billion for regionalized Alternative 94(a-f), which not only increases the original volume of waste by the largest percentage, but also increased the density of the final waste, thus causing mass-limited shipment, and also has the highest percentage of "double handled" waste. An estimate to handle RH waste for the decentralized baseline is also prepared. In addition to the $690.9 million estimated to transport CH waste for this alternative, $318.3 million is estimated to transport RH waste. Even though the volume of RH waste is significantly smaller than CH waste, to avoid exceeding radionuclide content limitations during transportation, a much smaller volume is carried by each shipment. The Transportation Cost Estimation Summary, Table 3-51 presents the estimated transportation costs for each alternative. The level of uncertainty in the cost estimates comes from two sources. One, the level of uncertainty in the stored and projected waste volumes in the BIR (DOE, 1995e) and two, the level of uncertainty in the studies used as guidance to develop the transportation cost estimates. For guidance in estimating transportation costs, a report titled "Waste Management Facilities Cost Information for Transportation of Radioactive and Hazardous Materials" (Feizollahi et al., 1994), was contracted by the DOE, and Revision 1 was completed in September 1994. A report of this nature would be classified as a "study estimate" (Peters and Timmerhaus, 1991), and would have a probable accuracy only within plus or minus 30 percent.

3.7.4.2.1 Backfill Emplacement Cost Results

Backfill emplacement costs are determined for each of the alternatives that specified backfill. The cost for emplacement activities is independent to the case of the alternative (decentralized, regionalized, centralized) and is only affected by the mass and volume of the backfill. Thus, costs for the alternatives are dependent only upon the amount and type of backfill that is to be utilized. Table 3-52 provides a summary of the estimated cost total for each alternative. The lowest cost for backfill are alternatives 77(b-d) which consists of the least amount of backfill material due to the reduced room height for waste. The highest cost for backfill are alternatives 35(a-b) and 94d, respectively. This is due to the increased complexity of emplacing a wet (grout) backfill.

Cost of backfill is categorized as a planning cost estimate and has an uncertainty of plus or minus 30 percent. In addition the estimation does not include the cost of the material to be utilized for backfill. It is assumed that backfill materials consisting of salt would utilize the existing mined materials.

3.7.4.2.2 WIPP Waste Operations Emplacement Cost Results

Cost information for the emplacement activities associated with the waste handling at the WIPP are discussed in this section. The discussion includes the assumptions and limitations of the results. The comparative analysis of the WIPP waste handling and emplacement activities is discussed is shown in Table 3-53. The cost of WIPP handling and emplacing the waste is

1

TABLE 3-51

TRANSPORTATION COST GRAND TOTAL SUMMARY

	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
CH Centralized Baseline	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 1	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 6	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 10	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 33	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 35	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 77	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 83	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 94	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 111	17,401	47,883,104	161,133	449,956	611,089
CH Regionalized Baseline	20356	54,395,038	188,497	512,795	701,291
CH Regionalized Alternative 1	19948	54,214,868	184,718	510,549	695,268
CH Regionalized Alternative 6	19253	51,234,016	178,283	483,104	661,387
CH Regionalized Alternative 10	17627	47,954,934	163,226	451,451	614,677
CH Regionalized Alternative 33	20356	54,395,038	188,497	512,795	701,291
CH Regionalized Alternative 35	20356	54,395,038	188,497	512,795	701,291
CH Regionalized Alternative 77	19948	54,214,868	184,718	510,549	695,268
CH Regionalized Alternative 83	20356	54,395,038	188,497	512,795	701,291
CH Regionalized Alternative 94	33598	89,825,730	311,117	845,163	1,156,280
CH Regionalized Alternative 111	20356	54,395,038	188,497	512,795	701,291
CH Decentralized Baseline	19974	53,744,480	184,959	505,929	690,888
RH Decentralized Baseline	7958	26,210,998	73,691	244,610	318,301
CH Decentralized Alternative 1	19602	53,672,290	181,515	504,689	686,204
CH Decentralized Alternative 6	18831	50,447,700	174,375	474,981	649,356
CH Decentralized Alternative 10	17203	47,259,152	159,300	444,134	603,433
CH Decentralized Alternative 33	19974	53,744,480	184,959	505,929	690,888
CH Decentralized Alternative 35	19974	53,744,480	184,959	505,929	690,888
CH Decentralized Alternative 77	19602	53,672,290	181,515	504,689	686,204
CH Decentralized Alternative 83	19974	53,744,480	184,959	505,929	690,888
CH Decentralized Alternative 94	33290	89,202,790	308,265	838,670	1,146,935
CH Decentralized Alternative 111	19974	53,744,480	184,959	505,929	690,888

TABLE 3-52

BACKFILL EMPLACEMENT COST TOTALS SUMMARY

Alternative ID#	Total Cost ($K)
33	55,527
35a	86,139
35b	86,141
77a	60,394
77b	31,299
77c	37,487
77d	35,894
83	53,146
94b	50,707
94c	78,536
94d	79,057
94e	42,262
94f	48,533
111	46,272

1 **TABLE 3-53**

WIPP WASTE HANDLING COSTS

Alternative	Configuration	Cost ($K)
Baseline[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040
1[b]	Decentralized	153,600
	Regionalized	153,600
	Centralized	153,600
6[b]	Decentralized	188,160
	Regionalized	188,160
	Centralized	188,160
10[b]	Decentralized	134,400
	Regionalized	134,400
	Centralized	153,600
33[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040
35 (a,b)[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040
77 (a-d)[b]	Decentralized	153,600
	Regionalized	153,600
	Centralized	153,600
83[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040
94 (a-f)[c]	Decentralized	175,718
	Regionalized	175,718
	Centralized	153,600
111[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040

Notes
[a]These alternatives involve only treating waste to WIPP WAC. WIPP emplaces waste for 35 years.
[b]These alternatives involve building new treatment facilities. WIPP emplaces waste for 25 years.
[c]This alternative involves building new treatment facilities. WIPP emplaces waste for 28.6 years for the decentralized and regionalized configurations, 3.6 years longer than the assumed operating life.

primarily independent of the cases (decentralized, regionalized, centralized) for this cost estimate study. For this estimate there were three waste handling/emplacement crew configuration that are utilized as input for the alternatives. The crew sized was dependent upon the number of TRUPACT-IIs that are processed per day. The number of TRUPACT-IIs that are processed based on the number of waste shipment and the limiting factor of a 35 year operational life for WIPP.

Baseline cost is established based on the required labor to handle and emplace the waste. The alternatives 33, 35(a-b), and 111 have the same comparable cost as the baseline. The alternative with the highest handling savings are number 10 and 94(a-f). This is due to a decrease in emplacement activities for 25 years rather than 35 years. Alternatives 1 and 6 have the same handling savings. Alternative 77(a-d) has a reduced savings as compared to alternative 1. This is due to the reduced room height but does not accommodate the current remote handled underground handling equipment or emplacement configuration. The limitation of this estimate is that the total WIPP budget is not included in this estimate. The only costs included are labor and anticipated capital equipment or modifications. Additional cost not included in this comparative analysis is the required budget that would be needed to manage and operate the WIPP, departmental management, and any additional research and development. This estimate is only intended to provide a measure of the relative cost savings or burden for an alternative.

3.7.4.3 Total Cost Summary

The total costs for implementing various alternatives are shown in Table 3-54. Total costs range from $4.0 billion for centralized treatment to WIPP WAC, to $7.7 billion for alternative 94c. Waste processing is by far the largest cost element, accounting for approximately 80 percent of the total cost.

3.7.4.4 Schedule Results

The results of the schedule development for the baseline and each of the different alternatives are presented in Figures 3-38 through 3-42. These schedules represent a "worst case" scenario where facilities needed to implement the baseline or alternatives are not currently available. It is assumed that where facilities currently exist, waste would be available for emplacement at WIPP in 1998. These figures present summary level schedules that include major activities and durations. Detailed schedules that list intermediate steps for each major activity and include all assumptions are included in Appendix Q, the schedule appendix.

Table 3-55 presents a summary comparison of the major activities and their associated start and finish dates for the baseline and each alternative. There is only a two year increase in total project duration between the baseline and the alternative with the longest duration (plasma). Operations are projected to begin in 11 to 12 years for alternatives that require new treatment facilities. Those facilities already available could begin treating waste immediately. For all alternatives, the treatment operations are projected to be completed within the anticipated operational lifetime of the WIPP facility. Based on schedules alone, no alternative presents significant benefits or detriments relative to the baseline.

Three major uncertainties associated with the schedules include:

1

TABLE 3-54

TOTAL COST SUMMARY

Alternative	Configuration	Costs ($K) Process[a]	Transportation	Backfill	Handling	Total
Baseline	Decentralized	3,576,954	690,888	0	215,040	4,482,882
	Regionalized	3,418,650	701,291	0	215,040	4,334,981
	Centralized	3,202,376	611,089	0	215,040	4,028,505
1	Decentralized	4,379,357	686,204	0	153,600	5,219,161
	Regionalized	3,974,696	695,268	0	153,600	4,823,564
	Centralized	3,411,991	611,089	0	153,600	4,176,680
6	Decentralized	4,117,678	649,356	0	188,160	4,955,194
	Regionalized	3,757,294	661,387	0	188,160	4,606,841
	Centralized	3,329,333	611,089	0	188,160	4,128,582
10	Decentralized	5,966,427	603,433	0	134,400	6,704,260
	Regionalized	4,992,885	614,677	0	134,400	5,741,962
	Centralized	3,960,139	611,089	0	153,600	4,724,828
33	Decentralized	3,576,954	690,888	55,527	215,040	4,538,409
	Regionalized	3,418,650	701,291	55,527	215,040	4,390,508
	Centralized	3,202,376	611,089	55,527	215,040	4,084,032
35a	Decentralized	3,576,954	690,888	86,139	215,040	4,569,021
	Regionalized	3,418,650	701,291	86,139	215,040	4,421,120
	Centralized	3,202,376	611,089	86,139	215,040	4,114,644
35b	Decentralized	3,576,954	690,888	86,141	215,040	4,569,023
	Regionalized	3,418,650	701,291	86,141	215,040	4,421,122
	Centralized	3,202,376	611,089	86,141	215,040	4,114,646
77a	Decentralized	4,379,357	686,204	60,394	153,600	5,279,555
	Regionalized	3,974,696	695,268	60,394	153,600	4,883,958
	Centralized	3,411,991	611,089	60,394	153,600	4,237,074
77b	Decentralized	4,379,357	686,204	31,299	153,600	5,250,460
	Regionalized	3,974,696	695,268	31,299	153,600	4,854,863
	Centralized	3,411,991	611,089	31,299	153,600	4,207,979
77c	Decentralized	4,379,357	686,204	37,487	153,600	5,256,648
	Regionalized	3,974,696	695,268	37,487	153,600	4,861,051
	Centralized	3,411,991	611,089	37,487	153,600	4,214,167
77d	Decentralized	4,379,357	686,204	35,894	153,600	5,255,055
	Regionalized	3,974,696	695,268	35,894	153,600	4,859,458
	Centralized	3,411,991	611,089	35,894	153,600	4,212,574
83	Decentralized	3,576,954	690,888	53,146	215,040	4,536,028
	Regionalized	3,418,650	701,291	53,146	215,040	4,388,127
	Centralized	3,202,376	611,089	53,146	215,040	4,081,651
94a	Decentralized	6,301,672	1,146,935	0	175,718	7,624,325
	Regionalized	5,502,932	1,156,280	0	175,718	6,834,930
	Centralized	4,217,091	611,089	0	153,600	4,981,780
94b	Decentralized	6,301,672	1,146,935	50,707	175,718	7,675,032
	Regionalized	5,502,932	1,156,280	50,707	175,718	6,885,637
	Centralized	4,217,091	611,089	50,707	153,600	5,032,487
94c	Decentralized	6,301,672	1,146,935	78,536	175,718	7,702,861
	Regionalized	5,502,932	1,156,280	78,536	175,718	6,913,466
	Centralized	4,217,091	611,089	78,536	153,600	5,060,316

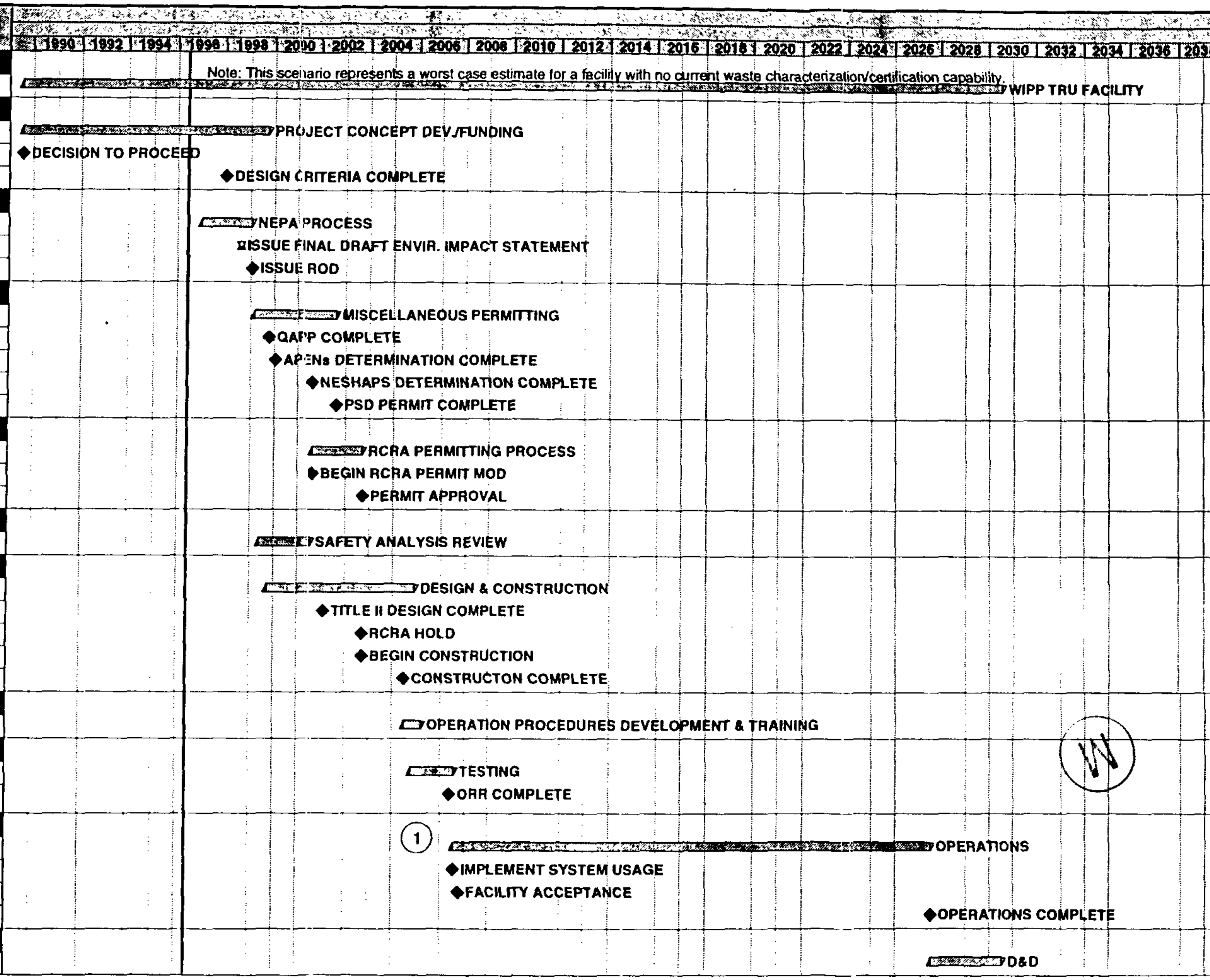
1 **TABLE 3-54 (Continued)**

TOTAL COST SUMMARY

		Costs ($K)				
Alternative	Configuration	Process[a]	Transportation	Backfill	Handling	Total
94d	Decentralized	6,301,672	1,146,935	79,057	175,718	7,703,382
	Regionalized	5,502,932	1,156,280	79,057	175,718	6,913,987
	Centralized	4,217,091	611,089	79,057	153,600	5,060,837
94e	Decentralized	6,301,672	1,146,935	42,262	175,718	7,666,587
	Regionalized	5,502,932	1,156,280	42,262	175,718	6,877,192
	Centralized	4,217,091	611,089	42,262	153,600	5,024,042
94f	Decentralized	6,301,672	1,146,935	48,533	175,718	7,672,858
	Regionalized	5,502,932	1,156,280	48,533	175,718	6,883,463
	Centralized	4,217,091	611,089	48,533	153,600	5,030,313
111	Decentralized	3,576,954	690,888	46,272	215,040	4,529,154
	Regionalized	3,418,650	701,291	46,272	215,040	4,381,253
	Centralized	3,202,376	611,089	46,272	215,040	4,074,777

[a]Process costs only represent those costs to process CH waste. Decentralized processing of RH waste costs approximately $1.0 billion.

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,451*	14JUL88A	13JUL29
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
190	ISSUE FINAL DRAFT ENVIR. IMPACT STATEMENT	0	12AUG97	11AUG97
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	881*	10MAR98	21AUG01
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		19JAN99
501	NESHAPS DETERMINATION COMPLETE	0		28AUG00
504	PSD PERMIT COMPLETE	0		21AUG01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	29AUG00	26SEP02
339	BEGIN RCRA PERMIT MOD	0	29AUG00	
430	PERMIT APPROVAL	0		26SEP02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,571*	25SEP98	22NOV04
266	TITLE II DESIGN COMPLETE	0		23FEB01
285	RCRA HOLD	0		26SEP02
289	BEGIN CONSTRUCTION	0	27SEP02	
291	CONSTRUCTON COMPLETE	0		01JUL04
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	02JUL04	17MAR05
TESTING				
507	TESTING	460*	28SEP04	18JUL06
530	ORR COMPLETE	0		19MAY06
OPERATIONS				
539	OPERATIONS	5,100*	19JUL06	21JUL26
560	IMPLEMENT SYSTEM USAGE	0	19JUL06	
565	FACILITY ACCEPTANCE	0	12OCT06	
567	OPERATIONS COMPLETE	0		21JUL26
D&D				
574	D&D	760*	22JUL26	13JUL29



* Represents a calculated time duration based on estimated scheduling values

(1) Baseline waste emplacement starts after WIPP is declared operational, the start date shown here represents the point in time when all WIPP WAC processing facilities are operational

Figure 3-38
Basecase Scenario Summary

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,681*	14JUL88A	07JUN30
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	899*	10MAR98	17SEP01
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		19JAN99
501	NESHAPS DETERMINATION COMPLETE	0		22SEP00
504	PSD PERMIT COMPLETE	0		17SEP01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	28NOV00	26DEC02
339	BEGIN RCRA PERMIT MOD	0	28NOV00	
430	PERMIT APPROVAL	0		26DEC02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,744*	25SEP98	28JUL05
266	TITLE II DESIGN COMPLETE	0		23MAY01
285	RCRA HOLD	0		26DEC02
289	BEGIN CONSTRUCTION	0	27DEC02	
291	CONSTRUCTION COMPLETE	0		08MAR05
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	09MAR05	18NOV05
TESTING				
507	TESTING	460*	02JUN05	22MAR07
530	ORR COMPLETE	0		25JAN07
OPERATIONS				
539	OPERATIONS	5,100*	23MAR07	25MAR27
560	IMPLEMENT SYSTEM USAGE	0	23MAR07	
565	FACILITY ACCEPTANCE	0	18JUN07	
567	OPERATIONS COMPLETE	0		25MAR27
D&D				
574	D&D	817*	26MAR27	07JUN30

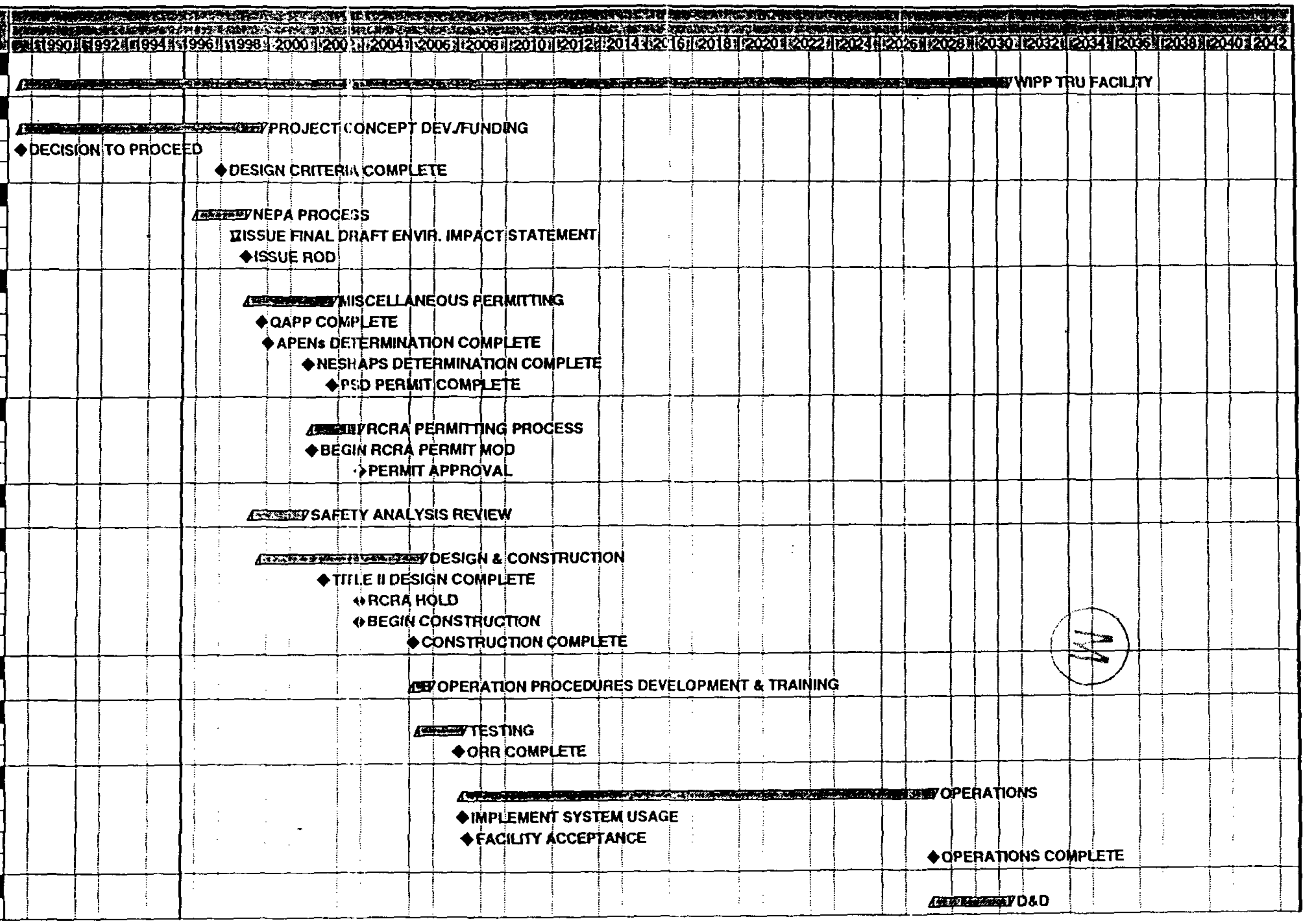


Figure 3-39
Supercompaction Scenario Summary

* *Represents a calculated time duration based on estimated scheduling values*

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,529*	14JUL88A	01NOV29
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	881*	10MAR98	21AUG01
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		19JAN99
501	NESHAPS DETERMINATION COMPLETE	0		28AUG00
504	PSD PERMIT COMPLETE	0		21AUG01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	29AUG00	26SEP02
339	BEGIN RCRA PERMIT MOD	0	29AUG00	
430	PERMIT APPROVAL	0		26SEP02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,621*	25SEP98	03FEB05
266	TITLE II DESIGN COMPLETE	0		23FEB01
285	RCRA HOLD	0		26SEP02
289	BEGIN CONSTRUCTION	0	27SEP02	
291	CONSTRUCTION COMPLETE	0		13SEP04
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	14SEP04	26MAY05
TESTING				
507	TESTING	460*	08DEC04	27SEP06
530	ORR COMPLETE	0		01AUG06
OPERATIONS				
539	OPERATIONS	5,100*	28SEP06	30SEP26
560	IMPLEMENT SYSTEM USAGE	0	28SEP06	
565	FACILITY ACCEPTANCE	0	22DEC06	
567	OPERATIONS COMPLETE	0		30SEP26
D&D				
574	D&D	788*	01OCT26	01NOV29

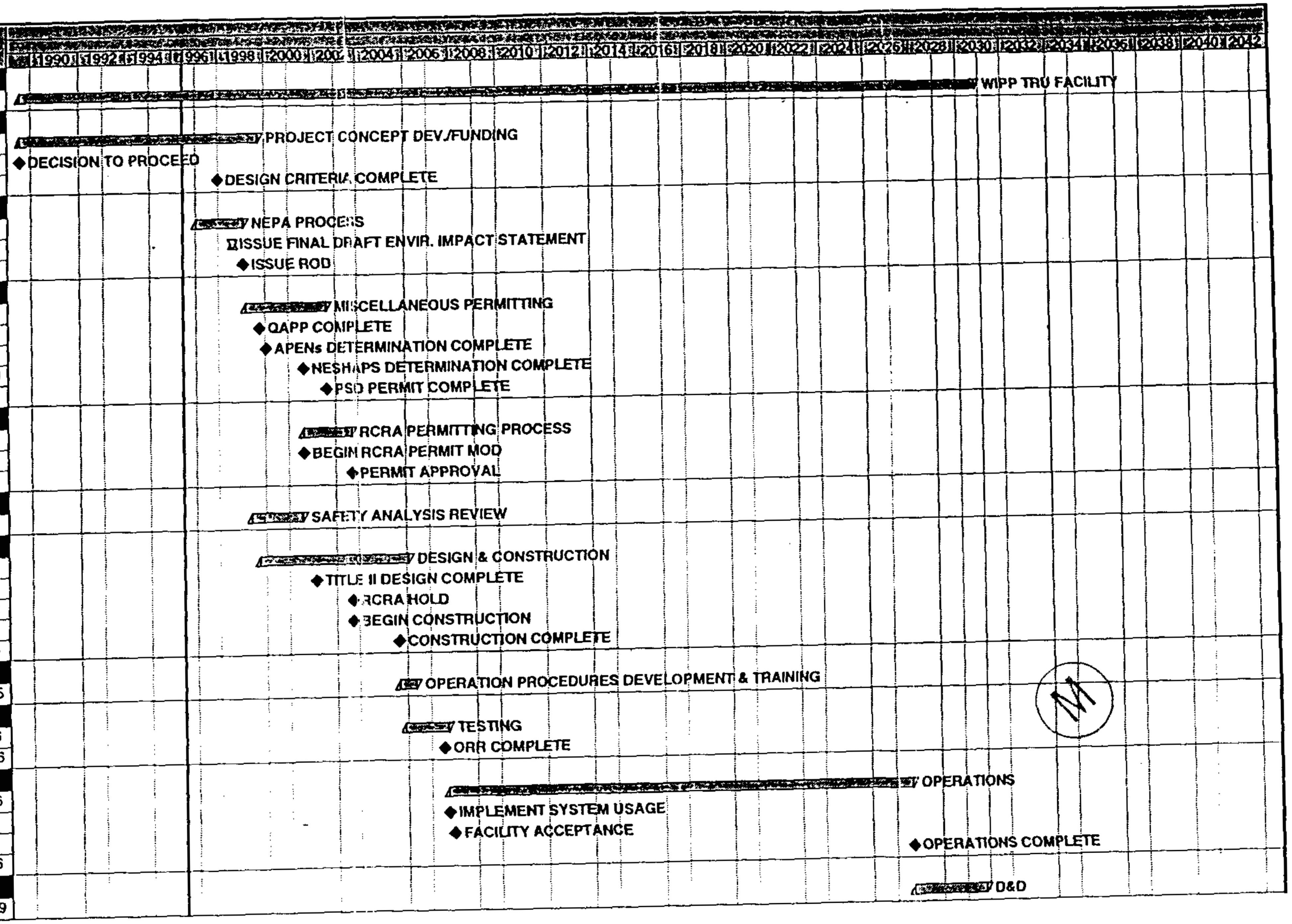


Figure 3-40

Shred & Compact Scenario Summary

* Represents a calculated time duration based on estimated scheduling values

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,903*	14JUL88A	22APR31
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	680*	04JAN96	01SEP98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	16MAR98	13MAR98
205	ISSUE ROD	0		01SEP98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	1,138*	10MAR98	23AUG02
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		15OCT99
501	NESHAPS DETERMINATION COMPLETE	0		30AUG01
504	PSD PERMIT COMPLETE	0		23AUG02
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	700*	22SEP00	20JUN03
339	BEGIN RCRA PERMIT MOD	0	22SEP00	
430	PERMIT APPROVAL	0		20JUN03
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,933*	25SEP98	25APR06
266	TITLE II DESIGN COMPLETE	0		28AUG01
285	RCRA HOLD	0		20JUN03
289	BEGIN CONSTRUCTION	0	23JUN03	
291	CONSTRUCTION COMPLETE	0		02DEC05
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	05DEC05	17AUG06
TESTING				
507	TESTING	460*	01MAR06	18DEC07
530	ORR COMPLETE	0		22OCT07
OPERATIONS				
539	OPERATIONS	5,100*	19DEC07	21DEC27
560	IMPLEMENT SYSTEM USAGE	0	19DEC07	
565	FACILITY ACCEPTANCE	0	14MAR08	
567	OPERATIONS COMPLETE	0		21DEC27
D&D				
574	D&D	850*	22DEC27	22APR31

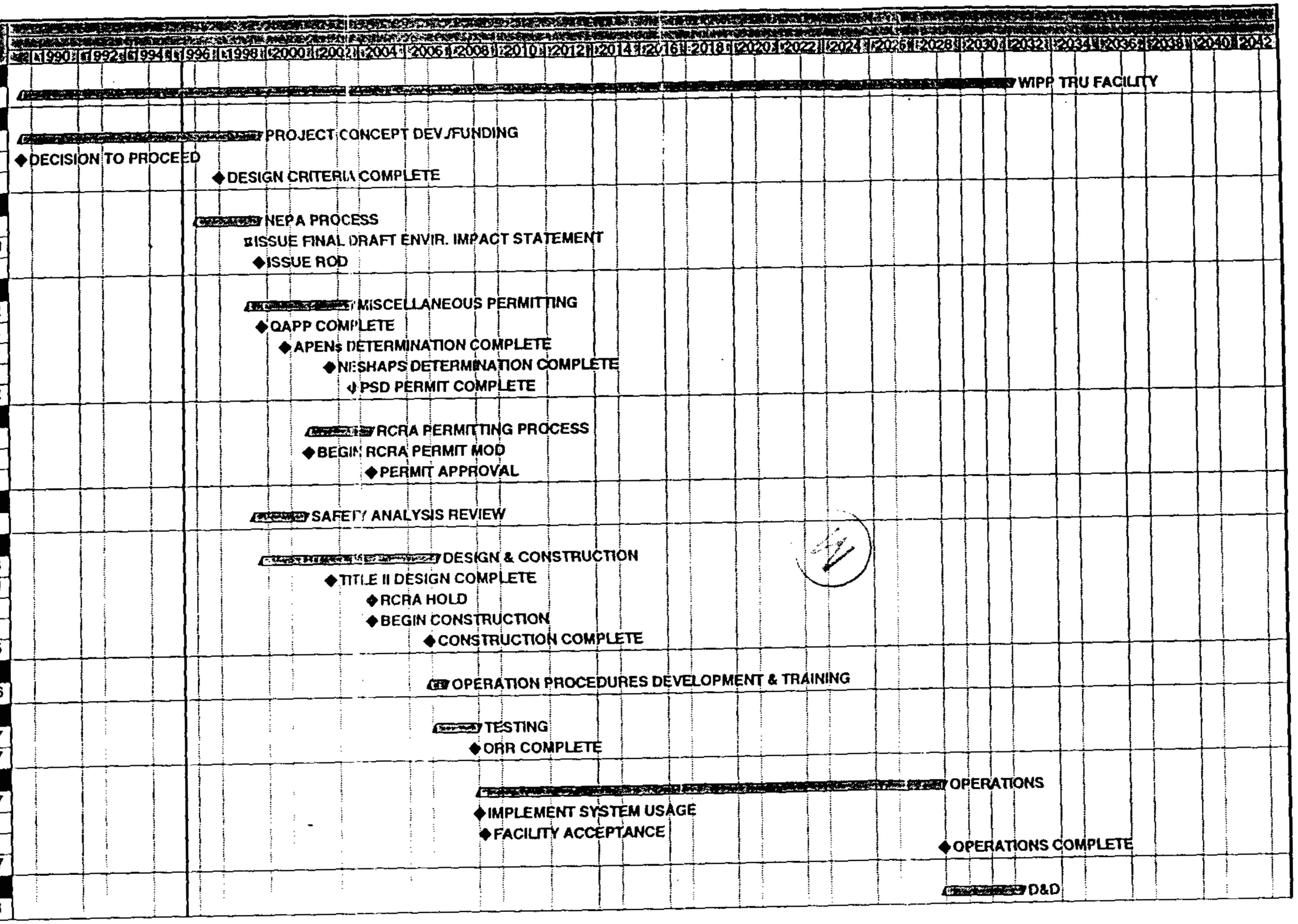
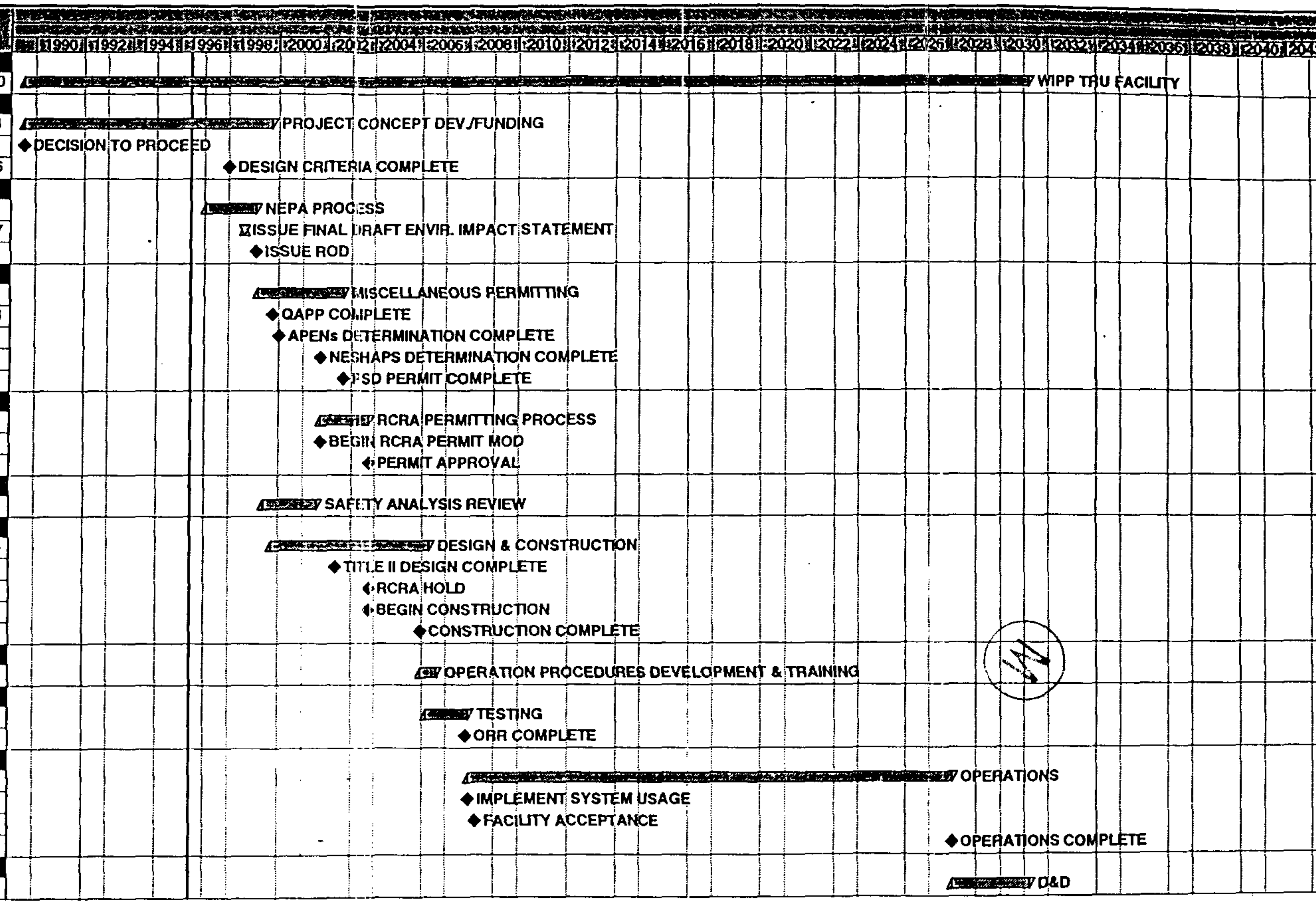


Figure 3-41
Plasma Scenario Summary

* *Represents a calculated time duration based on estimated scheduling values*

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,618*	14JUL88A	11MAR30
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	896*	10MAR98	12SEP01
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		19JAN99
501	NESHAPS DETERMINATION COMPLETE	0		19SEP00
504	PSD PERMIT COMPLETE	0		12SEP01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	20SEP00	17OCT02
339	BEGIN RCRA PERMIT MOD	0	20SEP00	
430	PERMIT APPROVAL	0		17OCT02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,686*	25SEP98	05MAY05
266	TITLE II DESIGN COMPLETE	0		08MAY01
285	RCRA HOLD	0		17OCT02
289	BEGIN CONSTRUCTION	0	18OCT02	
291	CONSTRUCTION COMPLETE	0		14DEC04
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	15DEC04	29AUG05
TESTING				
507	TESTING	460*	11MAR05	29DEC06
530	ORR COMPLETE	0		01NOV06
OPERATIONS				
539	OPERATIONS	5,100*	02JAN07	04JAN27
560	IMPLEMENT SYSTEM USAGE	0	02JAN07	
565	FACILITY ACCEPTANCE	0	27MAR07	
567	OPERATIONS COMPLETE	0		04JAN27
D&D				
574	D&D	812*	05JAN27	11MAR30



* *Represents a calculated time duration based on estimated scheduling values*

Figure 3-42
Cementation/Shred/ Add Clay Scenario

TABLE 3-55

PROCESSING SCHEDULE SUMMARY

Alternative	Description	Start	Finish	Years
6	Shred and Compact	1/4/96	11/1/2029	34
94	Cementation/Shred and Add Clay	1/4/96	3/11/2030	35
1	Supercompact	1/4/96	6/7/2030	35.5
10	Plasma	1/4/96	4/22/2031	36
N/A	Baseline	1/4/96	7/13/2029	33.5

- Availability of funding. Lack of funding could result in schedule delays.

- Ability of sites to obtain RCRA permits and other approvals and permits. For instance, it is anticipated that obtaining a RCRA permit for a plasma melter may be more difficult than obtaining one for some of the other processes. Additionally, there may be resistance at a given location to accepting waste from off-site, making it difficult to permit alternatives associated with the regionalized or centralized alternatives.

- Political climate, which could vary on a state-by-state basis.

These uncertainties are not quantified.

3.8 IMPACT ON OTHER WASTE DISPOSAL PROGRAMS

3.8.1 Definition of Factor 8

This factor includes an assessment of the impacts that the EAs will have on other waste processing and disposal programs, including programs for LLW and low-level mixed waste (LLMW). Major impacts are assessed based on additional volumes of waste that are projected to be generated by the TRU waste processing as analyzed for each waste processing based EA. EAs that do not process waste, such as backfill only EAs, are not considered in this analysis.

3.8.2 Methodology Used to Evaluate Factor 8

Data from four TRU waste cementation treatment processes at RFETS were analyzed, and the low-level secondary waste stream volumes were summed for each treatment process. The four waste generation rates, calculated as volume of low-level secondary waste generated per volume of cemented (output) waste, were then averaged (Appendix R). This average is 0.3 drums of secondary waste generated per drum of output cemented waste. The percents of the total secondary waste generated as LLW and LLMW are also averaged for the four treatment processes, and the average was approximately fifty percent LLW and fifty percent LLMW.

Because data are not available for other treatment processes, it is assumed that the other waste processes being evaluated (with the exception of plasma melting) generate similar volumes of secondary LLW as the cementation process, on a waste input basis. To convert the cementation data from an output basis to an input basis, the volume increase factor for cementation of 1:2.5 was used (see Table 3-47). This waste input basis factor, calculated to be 0.75 drums of secondary waste per drum of input waste, is then applied to each treatment process to calculate the volume of secondary LLW generated. The scaled volumes of sludges, solid organics, and solid inorganics that are used as inputs in the EA cost analysis were also used in this analysis (Section 2.3).

For the plasma melting process, the secondary low-level waste generation is assumed to be zero because the treatment process is designed such that secondary waste feeds back through the plasma melter. The volume reduction achieved in the plasma process for typical secondary wastes such as personal protective equipment (PPE), filters, and combustibles, is very high, so the volume of secondary wastes generated from the treatment process will be negligible. However, secondary waste will still be generated in the waste characterization step.

The waste characterization step is shown in the process flow diagrams in Section 3.7.2.1. The waste characterization module, as defined in the EM-PEIS, includes opening and sorting drum contents, collecting waste samples, and repackaging, if necessary, to remove and stabilize noncompliant waste. This operation, which occurs in a glovebox, is assumed to generate secondary low-level waste at the same rate (input basis) as the treatment processes. The secondary waste generated is calculated only for the portion of the waste inventory that passes through the waste characterization step (assumed to be 30 percent of stored waste and 10 percent of projected waste, as shown on the process flow diagrams in Section 3.7.2.1. Secondary waste generated from waste characterization is the same for the baseline and all EAs.

The calculated generation rates of LLW and LLMW for each EA were then compared to current and projected total DOE inventories of LLW and LLMW to determine impact in terms of percentage increase over current levels for each EA (Appendix R).

3.8.3 Assumptions and Data for Factor 8

The data analyzed for this factor comes from the RFETS Waste Stream and Residue Identification and Characterization report (WSRIC) (EG&G Rocky Flats, Inc., 1995), version 5.0. Four treatment processes are reviewed:

Building 774: Organic and Sludge Immobilization System (OASIS)
Building 774: Miscellaneous Waste Handling
Building 774: Precipitation/Filtration
Building 374: Sludge Solidification

All of these processes involve cementation of TRU waste and occur in gloveboxes. It is assumed that the RFETS data would generally be representative of TRU waste cementation processes at any DOE facility. Several other assumptions were made in assembling and compiling the data:

- All secondary waste characterized as "TRU or LL" is assumed to be LL, to estimate conservatively the potential impacts on the LL waste program. Likewise, waste characterized as "TRUM or LLM" is assumed to be LLM, and waste characterized as "LLM or HAZ" is assumed to be LLM.

- Several waste streams listed generation rates as "variable" or "insufficient data." Generation rates for these waste streams are estimated based on other similar processes and wastes.

- Most generation rates are provided on a volume basis. Those that are presented on a mass basis were converted to volume basis using assumed densities based on other RFETS data and the Baseline Inventory Report.

Other TRU waste processes at RFETS that parallel treatment options being evaluated in this study, such as the supercompactor, did not have secondary waste estimates provided in the WSRIC report. Because other data were not readily available, it is assumed that the other waste processes being evaluated (with the exception of plasma melting) generate similar volumes of secondary LLW as the cementation process, on a waste input basis.

Data for total DOE waste inventories and projections for LLW and LLMW are obtained from the 1993 Integrated Data Base Report (IDB) (DOE, 1994c) and the 1994 Mixed Waste Inventory Report (MWIR) (DOE, 1994d), respectively.

3.8.4 Results of Analysis of Factor 8

Table 3-56 presents the estimated volumes of secondary waste that are projected for each EA, including the amount calculated from the waste characterization and treatment steps. The annual waste generation shown is based on a 20-year treatment operation period for EA treatments. As explained in the methodology section, the secondary waste is assumed to be comprised of 50 percent LLW and 50 percent LLMW. Alternative 94 is projected to generate the most secondary

TABLE 3-56

SECONDARY WASTE VOLUMES
(cubic meters)

	Secondary Waste		LLW/LLMW (Each)	
Alternative	Total	Annual[1]	Total	Annual[1]
Baseline	32,729	1,636	16,365	818
1 and 77 (Supercompact)	118,040	5,902	59,020	2,951
6 (Shred and compact)	118,040	5,902	59,020	2,951
10 (Plasma)	21,848	1,092	10,924	546
94 (Enhanced cement/ shred and add clay)	131,625	6,581	65,813	3,291

[1]Based on a 20-year treatment operation period.

waste (three times more than the baseline), with Alternative 10 generating the least (one-third less than the baseline). Alternatives 1 and 6 generate 2.6 times more secondary waste than the baseline.

Table 3-57 shows a summary of LLMW impacts from each waste processing EA, expressed as percentages of total DOE LLMW (stored-plus-projected) and annual DOE LLMW generation. The annual DOE rate is taken as an average of projected generation rates for 1993 through 1997 from the MWIR. Projected generation rates beyond 1997 are not consistently provided in the MWIR. Alternative 10 (plasma) will generate less LLMW than the baseline, making this an attractive alternative in terms of impacts on other waste disposal programs. Compared to total DOE stored-plus-projected LLMW, the other alternatives will generate 14 to 16 percent more LLMW. The range for the annual generation basis is 10 to 12 percent more LLMW. This could have an impact on available permitted RCRA storage and treatment capacity at some sites.

Table 3-58 presents a summary of LLW impacts from each EA, expressed as percentages of total DOE LLW (buried-plus-projected) and annual DOE LLW generation. The annual DOE rate is taken as an average of projected generation rates for 1993 and 1994 from the IDB (the only years with annual generation rates projected). Again, Alternative 10 (plasma) generates less LLW than the baseline, making it an attractive alternative in terms of impacts on other waste disposal programs. Compared to total DOE LLW (buried-plus-projected), the other alternatives generate about one percent more LLW. The range for the annual generation basis is eight to nine percent more LLW. Because LLW can generally be shipped for disposal as it is generated, this increase is not expected to have as significant an impact on DOE's LLW program as the LLMW increase.

Uncertainties associated with this analysis of impacts on LLW and LLMW programs result from uncertainties in the source documents (WSRIC, MWIR, and IDB) as well as uncertainties introduced in this analysis. The IDB states that waste characterization is underway at many DOE sites, which may cause the classification of the waste to change in the future. In addition, the MWIR includes some waste from environmental restoration and D&D programs, while the IDB does not appear to. In this analysis, all EA treatments were assumed to generate secondary waste at the same rate (on an input basis) as four cementation processes at RFETS, which is felt to be a reasonable estimate for purposes of this analysis but which may require further study to reduce uncertainties.

TABLE 3-57
LOW-LEVEL MIXED WASTE IMPACTS

Alternative	% of Total DOE LLMW (Stored + Projected)[1]	% of Annual LLMW Generation[2]
Baseline	3.8	2.9
1 (Supercompact)	13.9	10.4
6 (Shred and compact)	13.9	10.4
10 (Plasma)	2.6	1.9
94 (Enhanced cement/shred and add clay)	15.5	11.6

[1]Based on stored and projected volumes from MWIR through 2022 (total = 425,932 m^3).

[2]Based on average of annual projected volumes from MWIR for 1993 to 1997 (average = 28,420 m^3/yr).

TABLE 3-58

LOW-LEVEL WASTE IMPACTS

Alternative	% of Total DOE LLW (Buried + Projected)[1]	% of Annual LLW Generation[2]
Baseline	0.29	2.2
1 (Supercompact)	1.03	7.8
6 (Shred and compact)	1.03	7.8
10 (Plasma)	0.19	1.4
94 (Enhanced cement/shred and add clay)	1.15	8.7

[1]Based on historical and projected buried waste volumes from IDB through 2022 (total = 5,722,000 m^3).

[2]Based on average of annual projected volumes from IDB for 1993 to 1994 (average = 37,895 m^3/yr).

4.0 QUALITY ASSURANCE

4.1 QUALITY ASSURANCE APPROACH

The DOE-CAO has developed a quality assurance (QA) program in the CAO Quality Assurance Program Description (CAO-QAPD; CAO-94-1012). The program meets the applicable requirements of the American Society of Mechanical Engineer's (ASME) "Quality Assurance Program Requirements for Nuclear Facilities" (NQA-1-1989 Edition), ASME's "Quality Assurance Requirements of Computer Software for Nuclear Facility Applications" (NQA-2a-1990 addenda, part 2.7 to ASME NQA-2-1989 edition), and ASME's "Quality Assurance Program Requirements for the Collection of Scientific and Technical Information on Site Characterization of High-Level Nuclear Waste Repositories" (NQA-3-1989 edition).

The ASME NQA-1-1989 edition sets forth requirements for the "establishment and execution of quality assurance programs for the siting, design, construction, operation, and decommissioning of nuclear facilities." For the purpose of this project, the NQA-2a-1990 addenda to ASME NQA-2-1989 edition standard applies to computer software "used to produce or manipulate data which are used directly in the design, analysis, and operation of structures, systems, and components." The NQA-3-1989 edition standard sets forth quality assurance requirements which apply to "activities which could affect the quality of scientific and technical information collected as part of the site characterization phase of high-level nuclear waste repositories."

The QA program implemented in support of the EACBS address elements such as calculations, models, and data collection used to perform the EA analysis. Documentation that details quality indicators such as data accuracy, precision, representativeness, completeness, comparability, and reproducibility has been compiled for the record, as appropriate. Appendix S details specific QA procedures used in most of the factors.

Computer models developed in support of the analyses in this study are based upon appropriate conceptual, mathematical, and numerical models. Program verification and validation methods were applied to ensure the desired performance of these models. Verification is the process by which the output (e.g., numerical results) of a computer program are determined to be "correct". Verification implies that the program solves the numerical problem as intended by the program author. Validation implies that the theory and assumptions used in constructing the program logic constitute a correct representation of the process or system being simulated by the program. Verification was performed by one, or more of the following methods, depending on the intended use of the program:

- Independent manual calculations are performed to verify the program algorithms.

- The results produced by the program are compared to the results from an "independently developed" program (e.g., a program developed outside the company or by an independent working group).

- The program results are compared to analyses published in textbooks and journals or, to the results of applicable experiments.

- Previous Validation. Models that have been previously used and approved in other DOE program will not be revalidated unless the model is modified or used for other purposes than their intended design.

Validation documentation, as necessary, consist of published conclusions comparing model predictions with data from laboratory experiments, field experiments, natural analogues, and published conclusions made by external review groups.

Many aspects of the EACBS are qualitative in nature. The methods used to analyze the EAs within the factors used many quantitative tools such as computer models and spreadsheet calculations (see appendices for details). However the results from these quantitative tools are qualitative since the input parameters and assumptions are based on qualitative estimates and judgements. The quality assurance program used in this report mostly centers around hand checking calculations from spreadsheets, computer models and validating changes made to these models.

5.0 INTEGRATION AND SUMMARY OF ANALYSIS RESULTS

5.1 OVERVIEW OF THE INTEGRATION PROCESS

The EAs proposed in this study are intended to reduce the estimated risks to future populations from waste disposal at WIPP and to provide additional confidence in the performance of the disposal system. EA evaluation factors 1 and 2 address these issues. The additional handling and processing of wastes required to implement the EAs may, however, impose additional near-term costs and health risks beyond those involved in the WIPP baseline design. These potential concerns are addressed by evaluation factors 3 through 8. This section integrates the results from all the evaluation factors into a form that will assist decisionmakers and other stakeholders in assessing the costs and benefits of EA adoption for both short and long-term impacts.

The next subsection reviews the TRU waste disposal program scenarios evaluated in detail for this study. Next, the quantitative performance measures used to document waste system performance against the evaluation factors found in Chapter 3 are described and organized for integrated results presentation. Finally, integrated results are presented in a form that allows the overall performance of the EAs to be compared to the baseline WIPP design.

5.2 SUMMARY OF EAs EVALUATED

The identification and screening of EAs is documented in Chapter 2. Out of 111 EA concepts screened for this analysis, 18 specific alternatives were selected for further evaluation. The 18 EAs represent a complete spectrum of EAs ranging from those believed to be narrowly effective in one impact area to those with broad effectiveness plus EAs judged to have high feasibility. Summary descriptions of the EAs selected for evaluation are presented in Section 2.2.1.

EAs involving additional waste processing were further evaluated under three separate configurations:

- Waste processing is decentralized at 10 generator sites.
- Waste is processed at 5 regional generator sites.
- Waste is centrally processed at WIPP.

This consideration of waste processing location expanded the number of EA scenarios to be evaluated to 44 plus the baseline case.

The EAs can be uniquely defined by the following three parameters:

- Combination alternatives
- Waste processing alternatives
- Waste backfill provisions

Figure 5-1 presents a scenario tree constructed using these parameters to organize the baseline and 44 evaluated EAs in a logical order . The scenario tree organization starts at the top with the baseline TRU disposal system. Next follows those EAs that involve only backfill external to the waste drums. EAs that use increasingly aggressive processing technologies are found by descending down the scenario tree.

TRU Disposal System	Additional Waste Processing?	Processing Facilities Location?	Waste Backfill?	Seq. No.	Engineered Alternative Case #
	None*	N/A	None	1	Baseline
			Sand+Clay	2	33
			SAG	3	35a
			CG	4	35b
			Clay	5	111
			CaO	6	83
	Super C	WIPP	None	7	1-1
			SAG	8	77a-1
			Clay	9	77b-1
			Sand+Clay	10	77c-1
			CaO	11	77d-1
		5 Sites	None	12	1-5
			SAG	13	77a-5
			Clay	14	77b-5
			Sand+Clay	15	77c-5
			CaO	16	77d-5
		10 Sites	None	17	1-10
			SAG	18	77a-10
			Clay	19	77b-10
			Sand+Clay	20	77c-10
			CaO	21	77d-10
	S&C	WIPP	None	22	6-1
		5 Sites	None	23	6-5
		10 Sites	None	24	6-10
	SCC	WIPP	None	25	94a-1
			Sand+Clay	26	94b-1
			CG	27	94c-1
			SAG	28	94d-1
			Clay	29	94e-1
			CaO	30	94f-1
		5 Sites	None	31	94a-5
			Sand+Clay	32	94b-5
			CG	33	94c-5
			SAG	34	94d-5
			Clay	35	94e-5
			CaO	36	94f-5
		10 Sites	None	37	94a-10
			Sand+Clay	38	94b-10
			CG	39	94c-10
			SAG	40	94d-10
			Clay	41	94e-10
			CaO	42	94f-10
	Plasma	WIPP	None	43	10-1
		5 Sites	None	44	10-5
		10 Sites	None	45	10-10

LEGEND:

Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
SAG: *Salt Aggregate Grout*
CG: Cemenitious Grout
* Baseline assumes processing to meet WIPP WAC is performed.

Figure 5-1
Engineered Alternatives Scenario Tree

5.3 PERFORMANCE MEASURES FOR RESULTS INTEGRATION

The baseline TRU waste disposal system and the 18 EAs defined in Chapter 2 were evaluated against each of the eight factors discussed in Chapter 3. In Chapter 3, analysis results were presented for each factor using quantifiable performance measures identified for each factor. While some factors were characterized by a single performance measure, others required several different performance measures to adequately describe the results. Table 5-1 summarizes the performance measures reported for each factor.

To facilitate the integration of results, the performance measures reported in Chapter 3 were organized and condensed to define a multi-element "impact vector" describing the complete analysis results for each EA for all factors. Special attention was given in constructing the impact vector to communicate the phase of the TRU disposal program being impacted by an EA and the location (at WIPP, at generator sites) of the risk or cost impact. The relationships between the eight assessment factors and the elements of the impact vector are shown in Figure 5-2.

5.4 SUMMARY OF ANALYSIS RESULTS FOR EVALUATED ALTERNATIVES

5.4.1 Approach to Results Integration

Figure 5-3 combines the EA scenario tree from Figure 5-1 and the impact vector from Figure 5-2 to form a matrix for integrating and summarizing the results of the EA analyses. To facilitate comparison of the EAs to the baseline WIPP design, the quantitative results from each factor analysis, expressed in the different units of measure as summarized in Table 5-1, are translated into a common qualitative scale that compares the EA to the baseline in general terms. Table 5-2 below shows the five categories that are used to represent the results of each impact vector element.

The term "significant" refers to the overlap in the range of performance predicted for the EA verses the baseline. Interpretation of these categories varies with the relative magnitude and uncertainty of the performance measures. For example, a factor of two difference between the predicted point estimates for total cost of alternatives may be very significant with essentially no overlap in the distributions of the two predictions. A factor of two difference in predicted point estimates for latent cancer fatalities may, by comparison, be less significant with a considerable overlap in the distributions of the two predictions. This concept is similar to the idea of statistical significance, however, it is assigned judgmentally in this report since we are addressing a state of knowledge rather than the results of controlled experiments.

Figure 5-4 presents the same qualitative ratings shown in Figure 5-3, only condensed down to *the eight top level elements of the impact vector.*

A summary of selected analysis results from each of the eight factors are presented in Table 5-3. Table 5-3 contains an overview of the analysis results for each EA and the baseline case. Supportive data for the results are also included.

The remainder of this chapter discusses how the quantitative evaluation results from Chapter 3 were interpreted for each of the major impact categories for presentation in Figure 5-3.

1 **TABLE 5-1**

PERFORMANCE MEASURES REPORTED

EA FACTOR	PERFORMANCE MEASURE	UNITS
1) Long term Repository Performance	Measure of relative effectiveness (MRE) of repository performance compared to the baseline.	Ratio of the mean value EA performance to the baseline
2) Uncertainty in Compliance Assessment	Measure of the relative uncertainty (MRU) of repository performance compared to the baseline.	Ratio of the range factor for EA performance to the baseline
3) Worker & Public Risk[a]	Facility worker risk	FTE-REM excess fatalities, construction and operation injuries and fatalities
	Maximum co-located worker risk	REM, excess cancer fatalities
	Co-located worker collective risk	Person-REM excess fatalities[b]
	Maximum off-site individual risk	REM, excess cancer fatalities
	Collective off-site public risk	Person-REM excess fatalities[b]
4) Impact on Waste Removal	Measure of relative difficulty of waste removal compared to the baseline.	Qualitative ranking.
5) Transportation Risk[a]	Transport crew collective radiological, nonaccident risk	Person-REM, latent cancer fatalities
	Public collective radiological, nonaccident risk	Person-REM, latent cancer fatalities
	Public maximum individual radiological, nonaccident risk	REM, latent cancer fatalities
	Public and crew collective radiological, accident risk	Person-REM, latent cancer fatalities
	Public and crew collective chemical risk	EPRG-2 ratio
	Public and crew collective non-rad, non-chemical risk	injuries, fatalities
6) Public Confidence	Listing of citizen concerns about repository performance	Not applicable
7) System Cost & Schedule[a]	Waste storage costs	1994 dollars
	Waste treatment costs	1994 dollars
	Waste transportation costs	1994 dollars
	WIPP waste placement and backfill costs	1994 dollars
	Start of WIPP operations	Date of first waste placement
	Completion of WIPP operations	Date of closure
8) Impact on Other Disposal Systems	Secondary waste volumes	Percentage change in estimated secondary waste volumes relative to the DOE low level and low level mixed waste

[a]For EAs that involve waste treatment, results are reported separately for decentralized, regionalized and centralized locations.
[b]Other units of measure are also used for non-radiological risk.

EA FACTORS	WIPP ENGINEERED ALTERNATIVES IMPACT VECTOR ELEMENTS																
	LONG TERM COMPLIANCE CONFIDENCE		PUBLIC HEALTH RISK				WORKER HEALTH		DISPOSAL SYSTEM COSTS					WIPP SCHEDULE		WASTE REMOVAL CAPABILITY	PUBLIC ACCEPTANCE
					At WIPP				TRU WASTE				OTHER WASTE				
											At WIPP						
	Cuttings Scenarios	Water Scenarios	At Generator	In Transport	*Before Closure*	*After Closure*	At Generator	At WIPP	At Generator	In Transport	Storage & Treatment	Placement & Backfill		First Waste to WIPP	Closure		
1) Long Term Repository Performance						X											
2) Uncertainty in Compliance	X	X															
3) *Worker & Public Risk*			X		X		X	X									
4) Waste Removal Capability																X	
5) Transportation Risk				X													
6) Public Confidence																	X
7) System Cost & Schedule									X	X	X	X		X	X		
8) *Other Disposal Systems*													X				

Figure 5-2
Relationship of EA Factors and Impact Vector

TRU WASTE DISPOSAL SCENARIO					WIPP ENGINEERED ALTERNATIVES IMPACT VECTOR ELEMENTS																
					LONG TERM COMPLIANCE CONFIDENCE		PUBLIC HEALTH RISK				WORKER HEALTH		DISPOSAL SYSTEM COSTS					WIPP SCHEDULE			
									At WIPP				TRU WASTE								
															At WIPP						
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Cuttings Scenarios	Water Scenarios	At Generator	In Transport	*Before Closure*	*After Closure*	At Generator	At WIPP	At Generator	In Transport	Storage & Treatment	Placement & Backfill	OTHER WASTE	First Waste	Closure	WASTE REMOVAL CAPABILITY	PUBLIC ACCEPTANCE
	None	None	1	Baseline-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
		Sand+Clay	2	33-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
		SAG	3	35a-1	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
		CG	4	35b-1	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
		Clay	5	111-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
		CaO	6	83-1	▲	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	□	▲	▲	▲	▲	▲
	Super C	None	7	1-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	□	▲	□	■	▲	○	▲
		SAG	8	77a-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	□	□	□	■	▲	○	▲
		Clay	9	77b-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	□	□	□	■	▲	○	▲
		Sand+Clay	10	77c-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	□	□	□	■	▲	○	▲
		CaO	11	77d-1	○	○	▲	▲	□	▲	▲	■	▲	▲	□	□	□	■	▲	○	▲
	S&C	None	12	6-1	▲	▲	▲	▲	□	▲	▲	■	▲	▲	□	▲	□	■	▲	▲	▲
	SCC	None	13	94a-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	▲	□	■	▲	▲	▲
		Sand+Clay	14	94b-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	□	□	■	▲	▲	▲
		CG	15	94c-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	□	□	■	▲	▲	▲
		SAG	16	94d-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	□	□	■	▲	▲	▲
		Clay	17	94e-1	○	▲	▲	▲	□	▲	▲	■	▲	▲	■	□	□	■	▲	▲	▲
		CaO	18	94f-1	○	○	▲	▲	□	▲	▲	■	▲	▲	■	□	□	■	▲	▲	▲
	Plasma	None	19	10-1	●	●	▲	▲	■	▲	▲	■	▲	▲	■	▲	○	■	▲	▲	▲

SCENARIO TREE LEGEND:

- Super C: Supercompaction of all waste, except sludges
- S&C: Shreding and compaction of all waste, except sludges
- SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
- SAG: Salt Aggregate Grout
- CG: Cemenitious Grout

IMPACT VECTOR RANKING:

- ● Performance is significantly better than the corresponding baseline performance.
- ○ Performance is marginally better than the corresponding baseline performance.
- ▲ Performance is approximately the same as the corresponding baseline performance.
- □ Performance is marginally worse than the corresponding baseline performance.
- ■ Performance is significantly worse than the corresponding baseline performance.

[a] The Centralized Processing Scenario was selected because it generally produces the lowest increase in cost, schedule impacts, and health risks with respect to the baseline case–results for the regionalized and decentralized scenarios are found in Section 3.0.

Figure 5-3
Summary of WIPP Engineered Alternative Evaluation Results for Centralized Processing Scenario[a]

TABLE 5-2

QUALITATIVE IMPACT VECTOR RESULT CATEGORIES

SYMBOL	DESCRIPTION
●	Performance is significantly better than the corresponding baseline performance.
○	Performance is marginally better than the corresponding baseline performance.
▲	Performance is approximately the same as the corresponding baseline performance.
□	Performance is marginally worse than the corresponding baseline performance.
■	Performance is significantly worse than the corresponding baseline performance.

TRU DISPOSAL SYSTEM SCENARIO					WIPP ENGINEERED ALTERNATIVES IMPACT VECTOR ELEMENTS								
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Cutings Scenarios Confidence	Water Scenarios Confidence	PUBLIC HEALTH RISK	WORKER HEALTH RISK	DISPOSAL SYSTEM COSTS	OTHER DISPOSAL SYSTEM IMPACTS	WIPP SCHEDULE	WASTE REMOVAL CAPABILITY	PUBLIC ACCEPTANCE
	None	None	1	Baseline-1	▲	▲	▲	▲	▲	▲	▲	▲	▲
		Sand+Clay	2	33-1	▲	▲	▲	▲	▲	▲	▲	▲	▲
		SAG	3	35a-1	○	▲	▲	▲	▲	▲	▲	▲	▲
		CG	4	35b-1	○	▲	▲	▲	▲	▲	▲	▲	▲
		Clay	5	111-1	▲	▲	▲	▲	▲	▲	▲	▲	▲
		CaO	6	83-1	▲	○	▲	▲	▲	▲	▲	▲	▲
	Super C	None	7	1-1	○	▲	▲	□	□	□	■	○	▲
		SAG	8	77a-1	○	▲	▲	□	□	□	■	○	▲
		Clay	9	77b-1	○	▲	▲	□	□	□	■	○	▲
		Sand+Clay	10	77c-1	○	▲	▲	□	□	□	■	○	▲
		CaO	11	77d-1	○	○	▲	□	□	□	■	○	▲
	S&C	None	12	6-1	▲	▲	▲	□	□	□	■	▲	▲
	SCC	None	13	94a-1	○	▲	▲	□	■	□	■	▲	▲
		Sand+Clay	14	94b-1	○	▲	▲	□	■	□	■	▲	▲
		CG	15	94c-1	○	▲	▲	□	■	□	■	▲	▲
		SAG	16	94d-1	○	▲	▲	□	■	□	■	▲	▲
		Clay	17	94e-1	○	▲	▲	□	■	□	■	▲	▲
		CaO	18	94f-1	○	○	▲	□	■	□	■	▲	▲
	Plasma	None	19	10-1	●	●	■	□	■	○	■	▲	▲

SCENARIO TREE LEGEND:

- Super C: Supercompaction of all waste, except sludges
- S&C: Shreding and compaction of all waste, except sludges
- SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
- SAG: Salt Aggregate Grout
- CG: Cemenitious Grout

IMPACT VECTOR RANKING:

- ● Performance is significantly better than the corresponding baseline performance.
- ○ Performance is marginally better than the corresponding baseline performance.
- ▲ Performance is approximately the same as the corresponding baseline performance.
- □ Performance is marginally worse than the corresponding baseline performance.
- ■ Performance is significantly worse than the corresponding baseline performance.

[a] The Centralized Processing Scenario was selected because it generally produces the lowest increase in cost, schedule impacts, and health risks with respect to the baseline case–results for the regionalized and decentralized scenarios are found in Section 3.0.

Figure 5-4

Condensed Summary of WIPP Engineered Alternative Evaluation Results for Centralized Processing Scenario[a]

TABLE 5-3

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Waste Backfill Compressive Strength (MPa)	NA	25.2	24.5	25.1	24.1	15.2	21.1	21.1	19.4	12.2	12.2	18.3	20.1	24.7	14.7	20.6	20.6	14.7	19.7	15.2
Emplacement Volume Impact (% Emplaced or Amount not Emplaced m^3)	NA	100% emplaced	100% empleced	100% empleced	100% emplaced	100% emplaced	100% emplaced	100% emplaced	41,655	41,655	41,655	41,655	100% emplaced	27,177	27,177	27,177	27,177	27,177	27,177	100% emplaced
Backfill Properties -																				
Initial Density (Kg/m^3)	NA	NA	NA	NA	NA	1,590	1,884	1,884	1,884	1,000	1,590	1,193	1,193	NA	1,590	1,884	1,884	1,000	1,193	1,000
Initial Porosity (%)						40.0	31.3	31.3	31.3	62.5	40.0	44.8	44.8		40.0	31.3	31.3	62.5	44.8	62.5
Solid Density (Kg/m^3)						2,650	2,741	2,741	2,741	2,670	2,650	2,162	2,162		2,650	2,741	2,741	2,670	2,162	2,670
MRE (unitless)	1																			
E1		1.0	0.93	0.95	0.00078	0.74	0.40	0.40	0.44	0.56	0.73	0.79	0.83	0.69	0.66	0.45	0.45	0.53	0.67	0.54
E2		1.0	1.4	1.1	0.0093	2.0	1.1	1.1	0.56	2.3	2.1	0.30	0.30	1.1	0.86	0.46	0.46	0.88	0.30	2.1
E1E2		1.0	1.0	1.0	0.00076	0.99	0.04	0.04	0.083	0.93	0.98	0.032	0.050	1.0	0.99	0.089	0.089	0.49	0.012	0.56
Cuttings		1.0	.26	0.79	0.12	0.92	0.40	0.40	0.21	0.22	0.21	0.22	0.94	0.57	0.52	0.30	0.30	0.53	0.54	0.94
Uncertainty E1	2																			
5th Percentile		NA	0.92	0.92	0.0004	0.73	0.40	0.40	0.43	0.55	0.72	0.60	0.83	0.68	0.64	0.44	0.44	0.52	0.26	0.53
95th Percentile			0.94	0.96	0.0012	0.78	0.42	0.42	0.47	0.59	0.78	0.81	0.84	0.72	0.69	0.47	0.47	0.56	0.68	0.55
Uncertainty E2	2																			
5th Percentile		NA	0.61	0.75	0.0009	0.31	0.18	0.18	0.091	0.45	0.37	0.009	0.009	0.19	0.14	0.03	0.03	0.16	0.005	0.33
95th Percentile			2.08	1.75	0.0549	1.99	1.09	1.09	0.87	2.35	2.06	0.83	0.84	1.08	1.61	0.88	0.88	1.62	0.75	2.18
Uncertainty E1E2	2																			
5th Percentile		NA	1.0	1.0	0.0003	0.99	0.009	0.009	0.011	0.37	0.98	0.012	0.012	0.37	0.22	0.01	0.01	0.024	0.009	0.024
95th Percentile			1.0	1.0	0.0066	0.99	0.75	0.75	0.98	0.98	0.98	0.438	0.76	1.0	0.99	0.98	0.98	0.99	0.045	0.99
Uncertainty Cuttings	2																			
5th Percentile		NA	0.25	0.75	0.11	0.91	0.40	0.40	0.21	0.21	0.21	0.21	0.94	0.56	0.52	0.29	0.29	0.53	0.53	0.93
95th Percentile			0.26	0.80	0.18	0.92	0.40	0.40	0.21	0.22	0.21	0.22	0.94	0.57	0.52	0.30	0.30	0.53	0.54	0.94
WIPP Worker Rad Risk	3																			
FTE-Rem		322.85	322.85	322.85	322.85	345.27	357.23	357 23	342 07	340.15	343.99	338.23	339.29	322.85	346.77	366.20	343.78	342.28	339.29	342.28
Excess Fatalities		0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.14	0.15	0.14	0.14	0.14	0.14
WIPP Indust. Accidents	3																			
Injuries		53.63	44.05	44.05	33.20	64.50	70.81	70 81	55 53	49 80	51 77	51.06	66.45	53 63	67.04	69 14	69.56	61.83	63.25	62.53
Fatalities		0.16	0.13	0.13	0.10	0.29	0.30	0.30	0.15	0.15	0.15	0.25	0.28	0.16	0.39	0.21	0.49	0.18	0.28	0.18

TABLE 5-3 (continued)

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Waste Processing Risk **Centralized Scenario**	3																			
Off-site Population																				
Cancer Fatalities		1.94×10^{-4}	$4..24\times10^{-4}$	4.24×10^{-4}	8.99×10^{-1}	NA	NA	NA	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	NA	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	NA
Cancer Incidence		5.51×10^{-8}	5.74×10^{-7}	5.74×10^{-7}	3.39×10^{-7}				5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}		5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	
Workers																				
Cancer Fatalities		7.78×10^{-1}	$1.10\times10^{+0}$	$1.20\times10^{+0}$	$1.34\times10^{+0}$				$1.10\times10^{+0}$	$1.10\times10^{+0}$	$1.10\times10^{+0}$	$1.10\times10^{+0}$		$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	
Cancer Incidence		1.30×10^{-5}	3.49×10^{-5}	3.80×10^{-5}	1.69×10^{-4}				3.49×10^{-5}	3.49×10^{-5}	3.49×10^{-5}	3.49×10^{-5}		3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	
Construct/Op Fatalities		2.81	3.79	4.08	5.29				3.79	3.79	3.79	3.79		4.08	4.08	4.08	4.08	4.08	4.08	
Waste Processing Risk **Regionalized Scenario**	3																			
Off-site Population		1.94×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	$4.79\times10^{+0}$	NA	NA	NA	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	NA	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	NA
Cancer Fatalities		5.51×10^{-8}	3.69×10^{-7}	3.69×10^{-7}	3.19×10^{-7}				3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}		3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	
Cancer Incidence																				
Workers		7.78×10^{-1}	9.92×10^{-1}	8.12×10^{-1}	9.10×10^{-1}				9.92×10^{-1}	9.92×10^{-1}	9.92×10^{-1}	9.92×10^{-1}		8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	
Cancer Fatalities		1.30×10^{-5}	3.15×10^{-5}	2.58×10^{-5}	3.73×10^{-5}				3.15×10^{-5}	3.15×10^{-5}	3.15×10^{-5}	3.15×10^{-5}		2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	
Cancer Incidence		2.81	3.83	3.45	7.18				3.83	3.83	3.83	3.83		3.45	3.45	3.45	3.45	3.45	3.45	
Construct/Op Fatalities																				
Waste Processing Risk **Decentralized Scenario**	3																			
Off-site Population		1.94×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	$4.60\times10^{+0}$	NA	NA	NA	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	NA	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	NA
Cancer Fatalities		5.51×10^{-8}	3.59×10^{-7}	3.59×10^{-7}	3.06×10^{-7}				3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}		3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	
Cancer Incidence																				
Workers		7.78×10^{-1}	9.54×10^{-1}	7.91×10^{-1}	$1.17\times10^{+0}$				9.54×10^{-1}	9.54×10^{-1}	9.54×10^{-1}	9.54×10^{-1}		7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	
Cancer Fatalities		1.30×10^{-5}	3.03×10^{-5}	2.51×10^{-5}	4.81×10^{-5}				3.03×10^{-5}	3.03×10^{-5}	3.03×10^{-5}	3.03×10^{-5}		2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	
Cancer Incidence		2.81	4.05	3.78	9.73				4.05	4.05	4.05	4.05		3.78	3.78	3.78	3.78	3.78	3.78	
Construct/Op Fatalities																				
Mining Advance Rate (m/Shift)	4	1.8	1.8	1.8	1.9	2.0	1.9	1.9	4.2	4.5	4.5	4.2	1.9	1.8	2.0	1.9	1.9	2.0	1.9	2.0
Removal Risk	4																			
Fatal Accidents		0.58	0.58	0.58	0.58	0.53	0.56	0.56	0.26	0.24	0.24	0.25	0.56	0.58	0.53	0.56	0.56	0.53	0.55	0.53
Non-Fatal Accidents		11.74	11.66	11.73	11.62	10.74	11.31	11.31	5.15	4.83	4.83	5.09	11.22	11.69	10.69	11.26	11.26	10.69	11.17	10.74

TABLE 5-3 (continued)

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Trans Rad Risk[1]	5																			
Decentralized (CH only)																				
Worker		$6.69\times10^{+2}$	$5.81\times10^{+2}$	$5.47\times10^{+2}$	$7.16\times10^{+2}$	$6.69\times10^{+2}$	$6.69\times10^{+2}$	$6.69\times10^{+2}$	$5.81\times10^{+2}$	$5.81\times10^{+2}$	$5.81\times10^{+2}$	$5.81\times10^{+2}$	$6.69\times10^{+2}$	$4.25\times10^{+2}$	$4.25\times10^{+2}$	$4.25\times10^{+2}$	$4.25\times10^{+2}$	$4.25\times10^{+2}$	$4.25\times10^{+2}$	$6.69\times10^{+2}$
Person-Rem		2.68×10^{-1}	2.32×10^{-1}	2.19×10^{-1}	2.86×0^{-1}	2.68×10^{-1}	2.6810^{-1}	2.6810^{-1}	2.32×10^{-1}	2.32×10^{-1}	2.32×10^{-1}	2.32×10^{-1}	2.6810^{-1}	1.70×10^{-1}	1.70×10^{-1}	1.70×10^{-1}	1.70×10^{-1}	1.70×10^{-1}	1.70×10^{-1}	2.6810^{-1}
LCF																				
Public		$4.00\times10^{+3}$	$3.47\times10^{+3}$	$3.27\times10^{+3}$	$4.27\times10^{+3}$	$4.00\times10^{+3}$	$4.00\times10^{+3}$	$4.00\times10^{+3}$	$3.47\times10^{+3}$	$3.47\times10^{+3}$	$3.47\times10^{+3}$	$3.47\times10^{+3}$	$4.00\times10^{+3}$	$2.55\times10^{+3}$	$2.55\times10^{+3}$	$2.55\times10^{+3}$	$2.55\times10^{+3}$	$2.55\times10^{+3}$	$2.55\times10^{+3}$	$4.00\times10^{+3}$
Person-Rem		$2.00\times10^{+0}$	$1.74\times10^{+0}$	$1.64\times10^{+0}$	$2.14\times10^{+0}$	$2.00\times10^{+0}$	$2.00\times10^{+0}$	$2.00\times10^{+0}$	$1.74\times10^{+0}$	$1.74\times10^{+0}$	$1.74\times10^{+0}$	$1.74\times10^{+0}$	$2.00\times10^{+0}$	$1.28\times10^{+0}$	$1.28\times10^{+0}$	$1.28\times10^{+0}$	$1.28\times10^{+0}$	$1.28\times10^{+0}$	$1.28\times10^{+0}$	$2.00\times10^{+0}$
LCF																				
Accident		$8.01\times10^{+1}$	$5.92\times10^{+0}$	$7.59\times10^{+1}$	$1.21\times10^{+0}$	$8.01\times10^{+1}$	$8.01\times10^{+1}$	$8.01\times10^{+1}$	$5.92\times10^{+0}$	$5.92\times10^{+0}$	$5.92\times10^{+0}$	$5.92\times10^{+0}$	$8.01\times10^{+1}$	$5.76\times10^{+1}$	$5.76\times10^{+1}$	$5.76\times10^{+1}$	$5.76\times10^{+1}$	$5.76\times10^{+1}$	$5.76\times10^{+1}$	$8.01\times10^{+1}$
Person-Rem		4.01×10^{-2}	2.96×10^{-3}	3.80×10^{-2}	6.05×10^{-4}	4.01×10^{-2}	4.01×10^{-2}	4.01×10^{-2}	2.96×10^{-3}	2.96×10^{-3}	2.96×10^{-3}	2.96×10^{-3}	4.01×10^{-2}	2.88×10^{-2}	2.88×10^{-2}	2.88×10^{-2}	2.88×10^{-2}	2.88×10^{-2}	2.88×10^{-2}	4.01×10^{-2}
LCF																				
Trans Chemical Risk	5																			
Decentralized																				
Max. Individual		$1.21\times10^{+0}$	$1.80\times10^{+0}$	$1.20\times10^{+0}$	2.10×10^{-5}	$1.21\times10^{+0}$	$1.21\times10^{+0}$	$1.21\times10^{+0}$	$1.80\times10^{+0}$	$1.80\times10^{+0}$	$1.80\times10^{+0}$	$1.80\times10^{+0}$	$1.21\times10^{+0}$	8.10×10^{-1}	8.10×10^{-1}	8.10×10^{-1}	8.10×10^{-1}	8.10×10^{-1}	8.10×10^{-1}	$1.21\times10^{+0}$
Trans Non-Rad/Chem Risk	5																			
Decentralized																				
Injuries		$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$	$6.61\times10^{+1}$
Fatalities		$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$	$4.87\times10^{+0}$
Percent of Comments Addressed by EA	6	NA	33%	33%	40%	31%	36%	36%	33%	33%	33%	33%	36%	42%	42%	42%	42%	42%	42%	36%
Total System Cost	7																			
Decentralized ($\times10^6$)		4,483	5,219	4,955	6,704	4,538	4,569	4,569	5,280	5,250	5,257	5,255	4,536	7,624	7,675	7,703	7,703	7,667	7,673	4,529
Regionalized ($\times10^6$)		4,335	4,824	4,607	5,742	4,391	4,421	4,421	4,884	4,855	4,861	4,859	4,388	6,835	6,886	6,913	6,914	6,877	6,883	4,381
Centralized ($\times10^6$)		4,029	4,177	4,129	4,725	4,084	4,115	4,145	4,237	4,208	4,214	4,213	4,082	4,982	5,032	5,060	5,061	5,024	5,030	4,075
Schedule Impact - Delayed Emplacement Relative to Baseline Startup	7	No Delay	9yrs.	8yrs.	9yrs.	No Delay	No Delay	No Delay	9yrs.	9yrs.	9yrs.	9yrs.	No Delay	9yrs.	9yrs.	9yrs.	9yrs.	9yrs.	9yrs.	No Delay
Other Waste Generation	8																			
Secondary (m^3)		32,729	118,040	118,040	21,848	32,729	32,729	32,729	118,040	118,040	118,040	118,040	32,729	131,625	131,625	131,625	131,625	131,625	131,625	32,729
LLW/LLMW (m^3)		16,365	59,020	59,020	10,924	16,365	16,365	16,365	59,020	59,020	59,020	59,020	16,365	65,813	65,813	65,813	65,813	65,813	65,813	16,365

[1]Only the Decentralized scenario is shown here. The Centralized scenario results for all EAs are the same as the baseline reported here. The Regionalized scenario analysis output is shown in Table 3-44.

In order to simplify the summary, only results for centralized processing scenarios from the Figure 5-1 EA scenario tree are included in Figure 5-3. This was done because, among the three processing facility schemes studied, centralized processing at WIPP generally produced the lowest increases in cost and schedule along with approximately comparable health risks. The impacts of regionalized and decentralized processing on cost are discussed in section 5.4.5.

5.4.2 Long-term Compliance Confidence

Chapters 3.1 and 3.2 report the evaluation of potential material releases from WIPP, given human intrusion into the repository in the distant future. These chapters discuss the impact of the EAs on the best estimate of WIPP performance and our confidence in the best estimate predictions, respectively.

The evaluations in chapters 3.1 and 3.2 focus on the possible transport of waste material from WIPP via direct removal by drilling and indirect removal via the transport of contaminated brine. Because the drilled material is removed from the bore hole directly into the above ground environment, while contaminated brine is subject to dilution and retention in the water bearing strata between the repository and the surface, evaluation results for these two release mechanisms are reported separately. Ongoing performance assessment work is now in progress that may produce conclusions on the relative importance of these release mechanisms.

Figures 5-5a and 5-5b show the predicted performance for all EAs relative to the baseline for direct material releases and the three brine transport scenarios. Figure 5-5a compares the median value results and Figure 5-5b compares the 95th percentile results.

Since no EA alters the footprint of the disposal area of the repository, EAs that reduce the effective diameter of the borehole through the waste should show the best improvement in predicted performance for direct drilling releases. The effective diameter of the borehole can, in theory, be reduced from the baseline conditions by increasing the shear strength of the waste bearing material, thereby causing the drill to cut a "cleaner" hole through the waste. Following this line of reasoning, EAs involving cement backfills and the supercompacting or plasma processing of waste should be expected to produce improved performance. This prediction was confirmed by the analysis results in Section 3.2. The reduction shown for plasma processing (approximately a factor of 9) was near the maximum achievable, considering the assumed increase in the effective borehole radius for unprocessed waste was a factor of 3. As stated in Section 3.1.1, it was not feasible to consider the impacts of actinide sorption on clays, EAs that employ clay based materials may exhibit better performance than the results presented in this report.

Repository performance with respect to brine transport is a much more complex question than direct material removal and was found to be dependent on the particular release scenario modeled. For the case where drilling passes through the repository and into the Castile brine reservoir below WIPP, plasma processing (EA#10) and EAs using cementitious backfills (EAs 35a, 35b, 77a, 94c, and 94d) produced a notable improvement over the baseline case.

For release scenarios where brine was modeled to pass through the waste horizontally before exiting (scenarios E2 and E1E2), the solubility of radionuclides and permeability of the waste were shown to be important. For release scenario E2, EAs using CaO backfill (EA#77d, 83 and 94f) produced marginally improved performance over the baseline. For release scenario E1E2, both

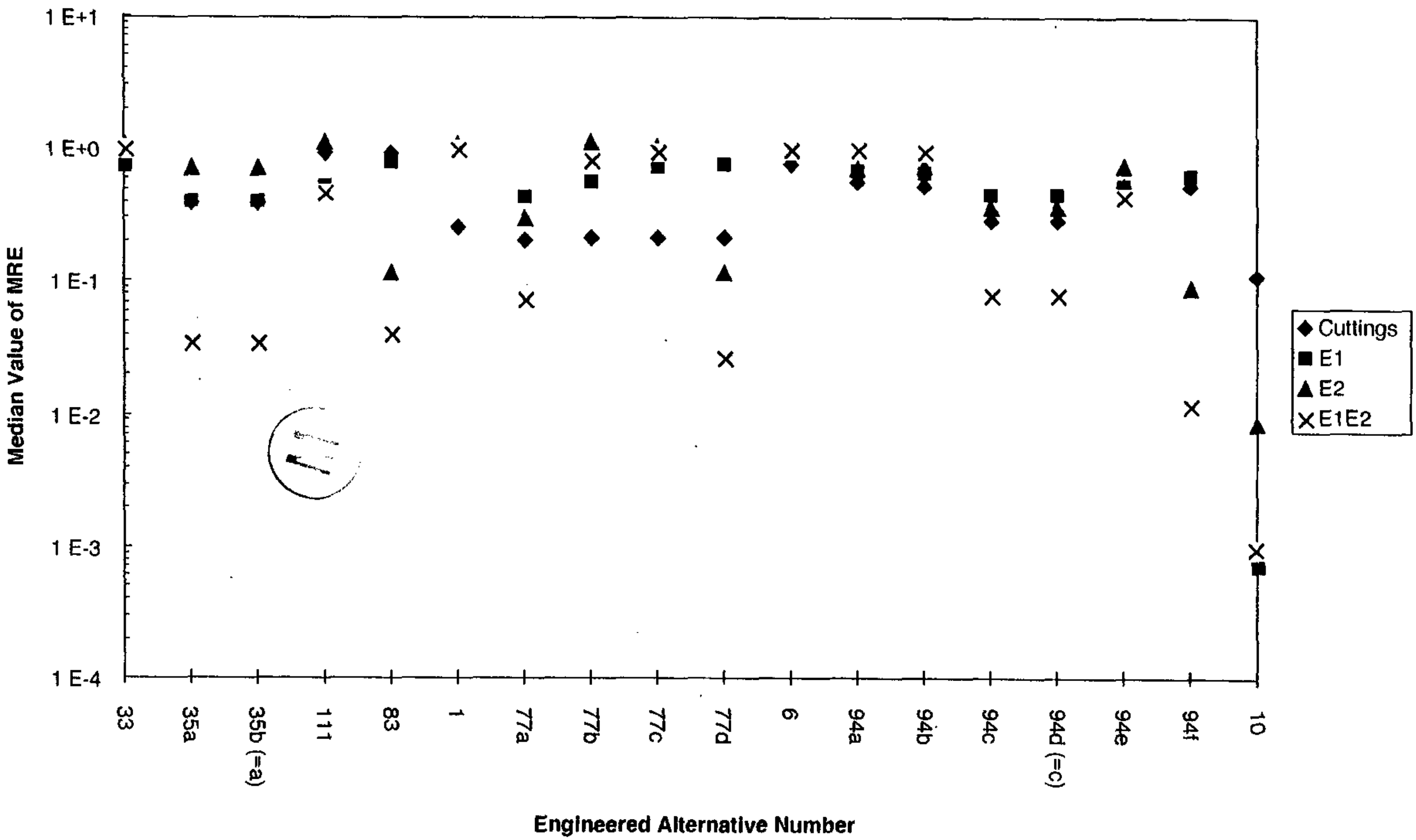


Figure 5-5a

Comparison of Medians of Case-by-Case MREs Across All Scenarios

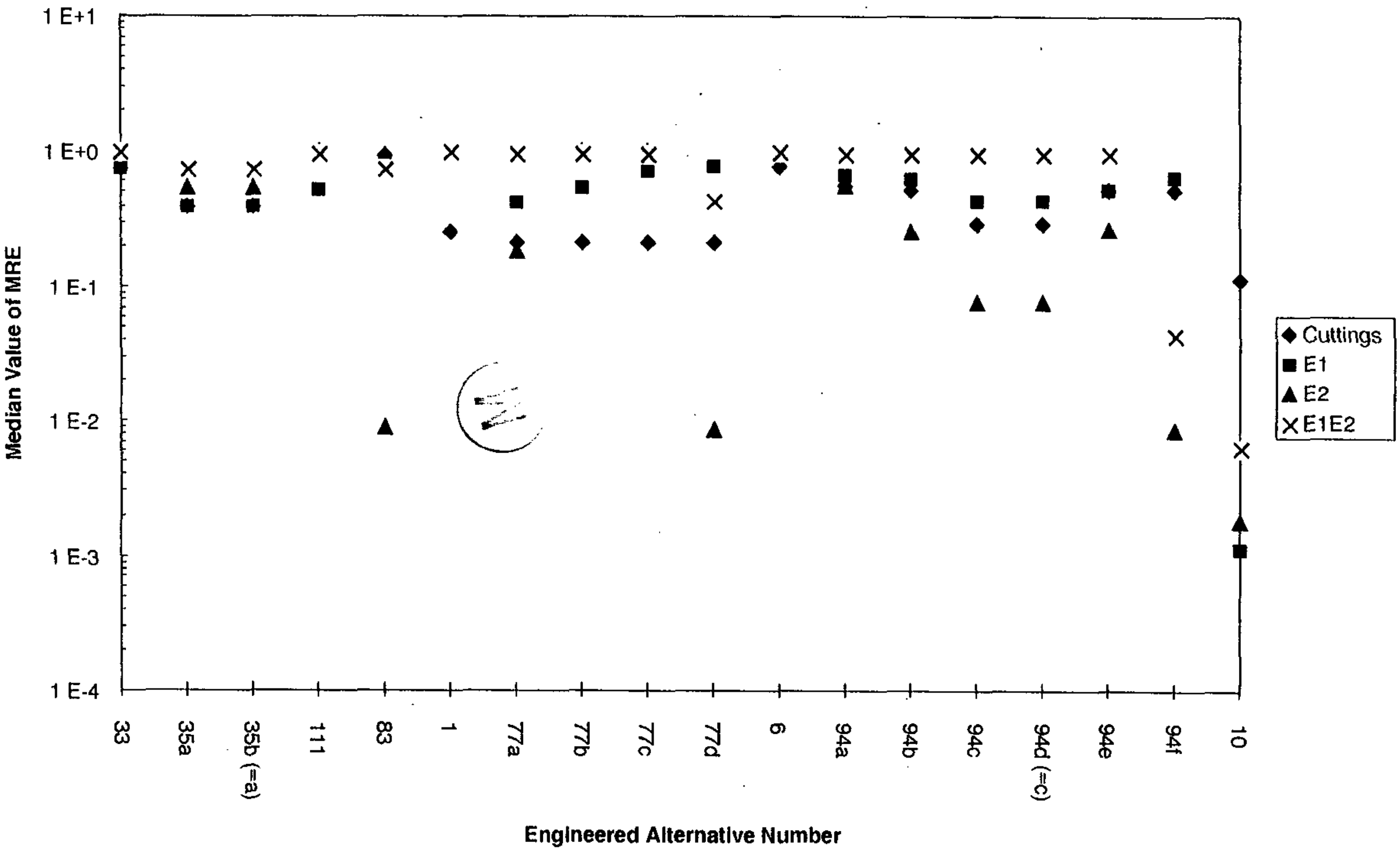


Figure 5-5b
Comparison of 95th Percentiles of the CDFs Across All Scenarios

CaO and cementitious backfills (EA#35a 35b, 77a, 77d, 83, 94c, and 94f) produced significant performance improvements. Plasma processing showed increased performance for both the E2 and E1E2 scenarios.

The qualitative performance rankings for brine transport scenarios in Figure 5-3 were assigned based on a combination of the results across the three brine transport scenarios. Based on the above discussion, Plasma Processing (EA#10) was given a "significant" rating because of its improvement in performance for all three brine transport scenarios. CaO backfill options (EA#77d, 83, and 94f) were given a "marginal" rating based on their improvements in both E2 and E1E2 release scenarios. All other EAs were rated generally unchanged from the baseline.

5.4.3 Public Health Risk

5.4.3.1 Public Health Risk Before Closure

Off-site public health risk from potential exposure to radionuclides and hazardous chemicals before WIPP closure was estimated for the baseline WIPP design and each EA. Calculations were performed to estimate added risks for both a hypothetical maximum exposed individual (MEI) and the collective off-site population. Relative risk indications among the EAs were consistent using either of these measures.

Total public health risk results for all EAs except those involving plasma waste processing were found to be quite close to the baseline predictions. Plasma waste processing (EA#10) public risk was found to be approximately four orders of magnitude greater than that for the other TRU processing options.

Public health risks at the generator sites were found to be relatively consistent across all scenarios (except plasma processing) due to the fact that processing risks added only marginally to the risk involved in waste handling and packaging found in the baseline alternative.

Public health risks at WIPP were higher, compared to the baseline, for scenarios requiring centralized waste processing at WIPP. This would be expected because the baseline has very minimal above ground waste handling at WIPP, while centralized processing will require extensive new treatment and disposal facilities at WIPP. This increased health risk at WIPP is partially offset, however, by lower risk at the generator sites, because the handling and packaging requirements for pre-treatment waste transfer are less than for direct placement at WIPP. The resulting total public risk across all sites for the centralized processing scenarios was generally found to be higher than for regionalized or 10-site processing. Based on the above findings, the results reported in Figure 5-3 show public health risk at the generator sites to be essentially unchanged for all EAs. Public health risks at WIPP are unchanged for the backfill only scenarios and marginally higher for all processing options, except plasma, which is significantly higher. These indicated increases in risk at WIPP are for the centralized processing options shown. For regionalized and decentralized cases, overall public health risks are marginally higher than that for the baseline.

Public health risk results are presented graphically in Figure 5-6 for all waste processing EAs. Backfill EAs (EA Nos. 33, 35a, 35b, 83, and 111) have the same risk as the baseline case. In this display, the total additional point estimate fatality risks from Tables 3-9 to 3-21 are summed to form the midpoints shown and the high and low values estimated by assigning a range factor of 2 to the distribution of possible outcomes around the point estimate values.

5.4.3.2 Transportation Risk

Transportation risks reported in Chapter 3.5 included the potential consequences to both the transport crew and the public from both radiological and nonradiological sources. Differences among the EAs were found for radiological and hazardous chemical exposure risks. However, these risks were dominated by nonradiological/nonchemical risks and the results for total excess fatalities showed only minor variations from the baseline (less than 8%) across all EA scenarios. Thus, transportation risks prior to WIPP closure are indicated as unchanged from the baseline for all EAs in Figure 5-3.

Transportation risk results are presented graphically in Figure 5-7. In this display, the total additional point estimate fatality risks from Tables 3-42, 3-43, and 3-43 are summed to form the best estimate values shown.

5.4.3.3 Public Health Risk After Closure

Estimates of the impact of the EAs on predicted long-term public heath risk, presented in Chapter 3.1, mirror the compliance results discussed in section 5.4.2. However, the magnitude of long-term health risks predicted for the baseline and all EAs are exceedingly small. Therefore, long-term public health risks for all EAs are classified as essentially the same as the baseline.

5.4.4 Worker Health Risk

Worker risks were estimated for both facility workers directly involved in handling and processing TRU wastes and for co-located workers not directly involved with the wastes.

Health risks to both facility and on-site co-located workers from potential exposure to radionuclides and hazardous chemicals was estimated for the baseline WIPP design and each EA. Calculations were performed to estimate added risks for both a hypothetical MEI and the collective on-site population. Relative risk indications among the EAs were consistent using either of these risk measures. Risks to facility workers from standard industrial hazards involved in facility construction and operation were also calculated. For all scenarios, standard industrial risks outweighed risks from exposure to radionuclides or hazardous chemicals.

Total worker health risk results for all EAs involving all types of waste processing were found to be higher than for nonprocessing scenarios. These higher risks were incurred at the processing sites, that is the generators for distributed or regionalized processing and at WIPP for centralized processing. As a result, the centralized processing cases reported in Figure 5-3 show unchanged risks for the generator sites and significantly higher risks at WIPP for all processing options.

Worker health risk results are presented graphically in Figure 5-8. In this display, the total additional point estimate fatality risks from Tables 3-9 to 3-21 are summed to form the midpoints shown and the high and low values are estimated by assigning a range factor of 2 to the distribution of possible outcomes around the point estimate values.

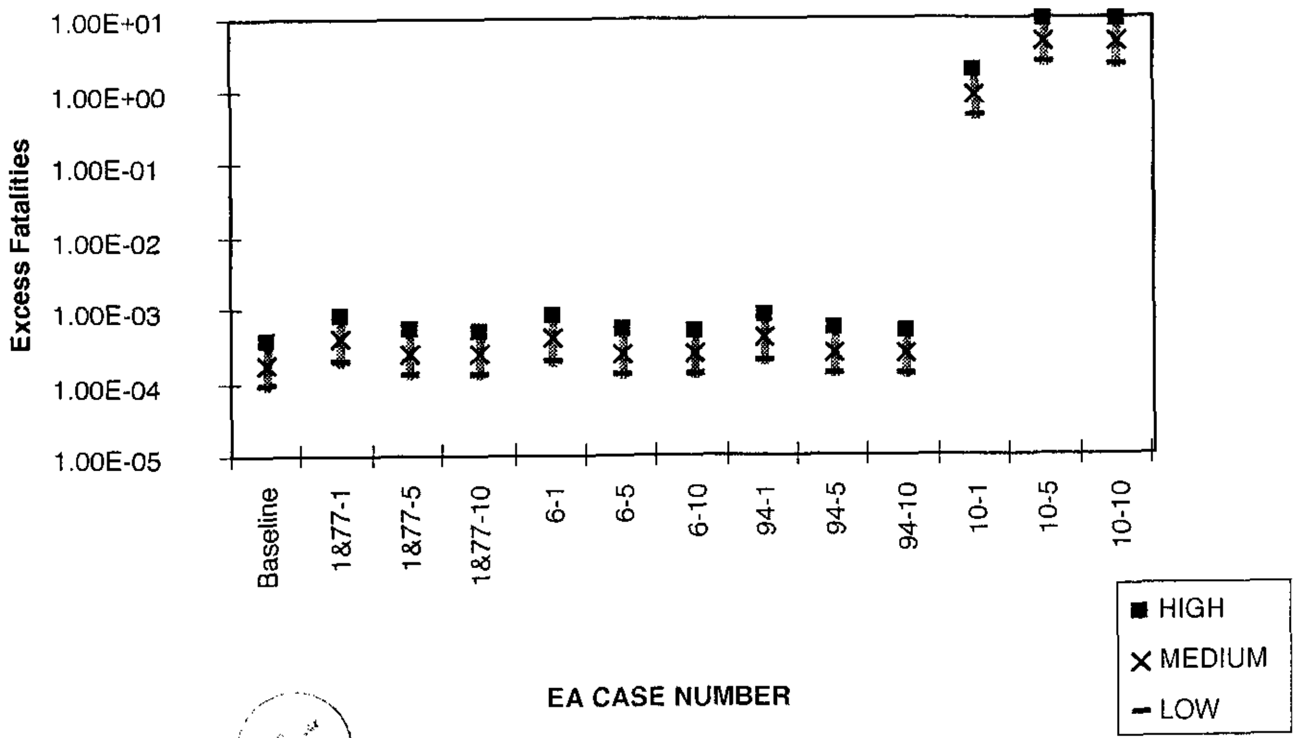


Figure 5-6
Offsite Public Risk

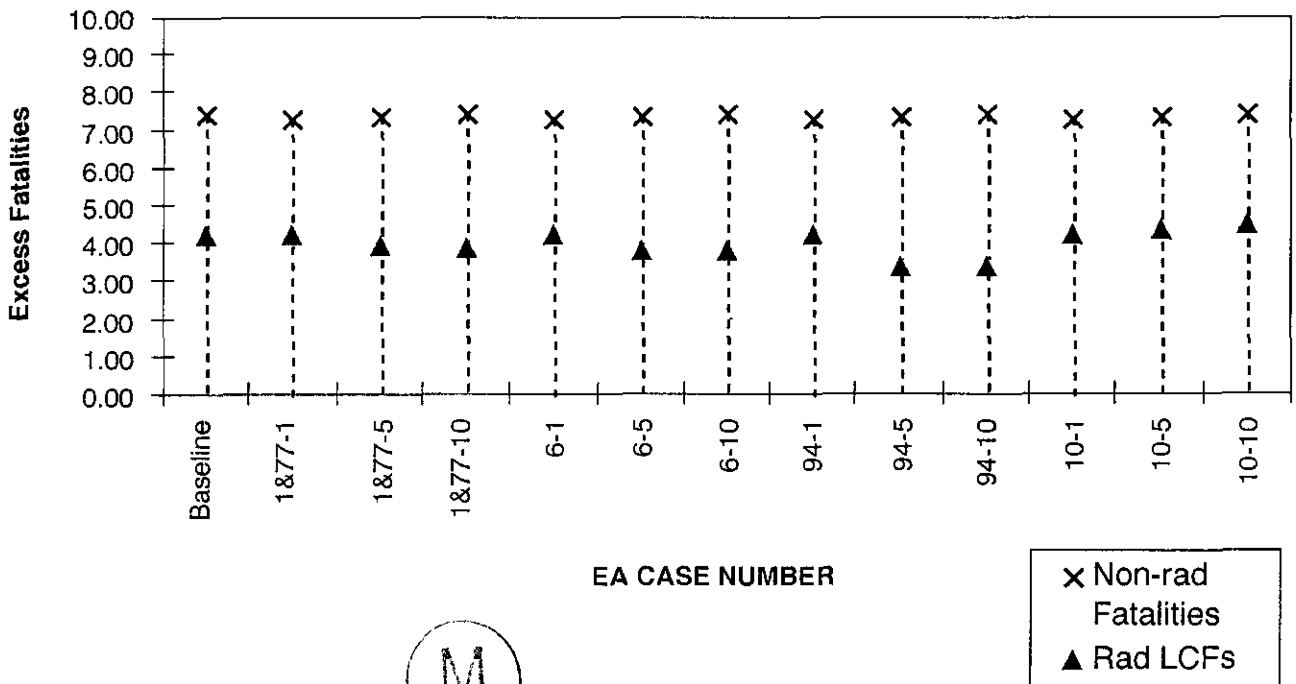


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Figure 5-7
Transportation Risk

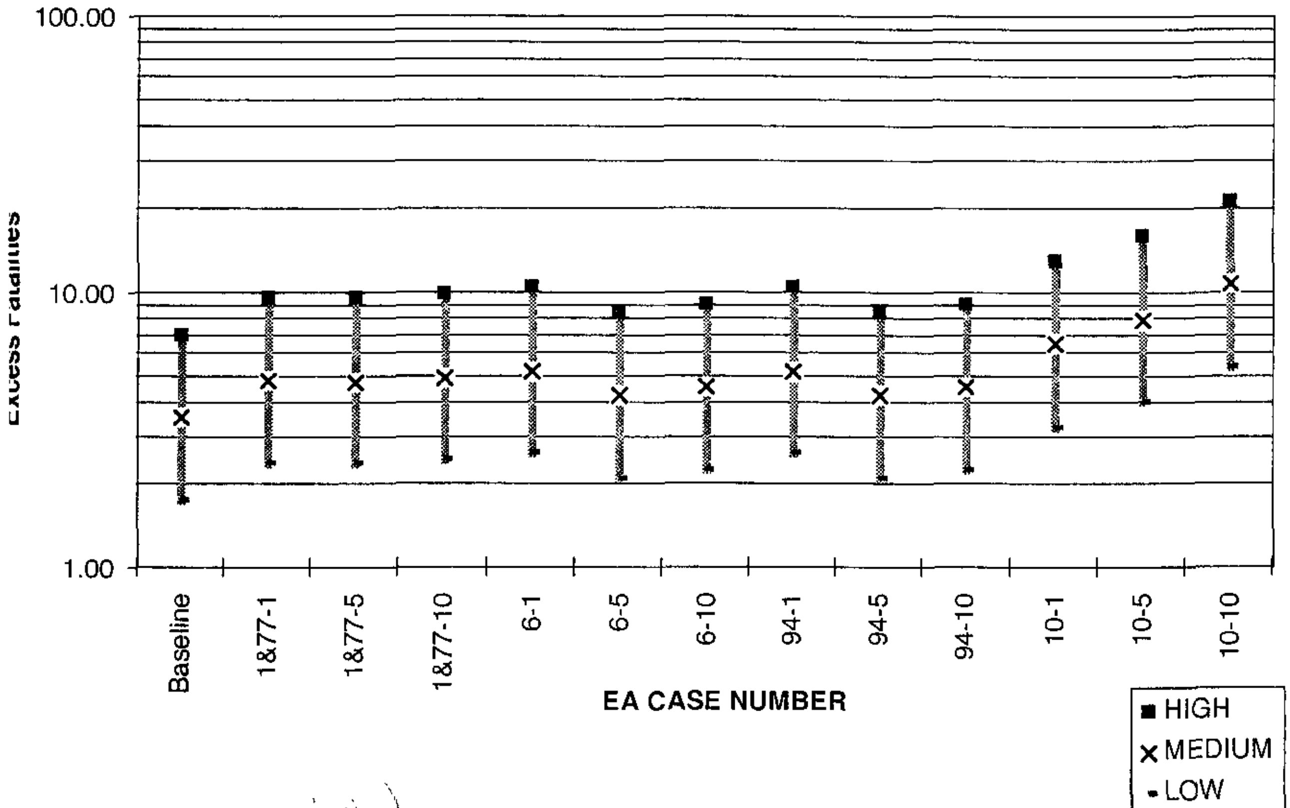

Figure 5-8
Worker Risk

5.4.5 Disposal System Cost

5.4.5.1 Waste Processing Cost

Estimated costs for waste processing summarized in Chapter 3.7.4.1.1 were found to increase substantially over the baseline for the more extensive processing methods. Overlaid on this trend, powerful economies of scale are predicted for accomplishing the processing centrally at WIPP rather than regionally or at each waste generation site. Centralized processing at WIPP, while potentially reducing overall costs, would result in significantly increased expenditures at WIPP. This shift is estimated to total between 15% and 34% of total processing costs or $500 million to $1.5 billion.

5.4.5.2 Transportation Cost

Waste transportation costs were found to be essentially the same for all centralized and backfill only EAs. These costs were estimated to be the same as the baseline centralized transportation costs. The decentralized and regionalized baseline costs were the same for the corresponding EAs except for the 94 series which had a significantly higher cost.

5.4.5.3 Waste Placement and Backfill Cost

Cost impacts for waste placement and backfill are estimated to total between $30 and $80 million or less than 1.5% of the total disposal system costs. The cost additions indicated on Figure 5-3 are incurred for the placement of wet cement backfills, while potential savings are shown for EA Nos. 1, 6, 10, 77 all, and 94 all processing options.

5.4.5.4 Total TRU Disposal System Cost

By combining the costs from the previous subsections, the combined influences of processing method and processing location on the total TRU waste disposal system costs can be seen. The impact of processing costs on the total TRU system is seen in Figure 5-9. This Figure shows the total TRU system costs, with uncertainty for all processing options performed centrally at WIPP. Supercompaction with backfill EAs (EA#77 all) and the shred and add clay alternatives (EA#94) show significant cost increases over the baseline. This conclusion is valid, however, only for the centralized processing results shown. Figure 5-10 shows that economies of scale are much stronger for the more aggressive processing methods than for the baseline. Thus, while centralized shred and add clay (EA#94) and plasma processing (EA#10) appear competitive with lesser processing alternatives, a decentralized approach for the same processes is significantly more costly.

5.4.6 Impact on Other Waste Programs

In general, only the additional waste processing activities associated with the WIPP EAs have the potential to impact other waste systems. The assessment of other waste system impacts reported in Chapter 3.8 found that all processing techniques evaluated, except plasma processing, significantly increased the LLW and LLMW volumes generated from the TRU waste disposal system. Plasma processing (EA#10) actually reduces somewhat the volumes of other waste from the base since all contaminated materials are recycled into the final product.

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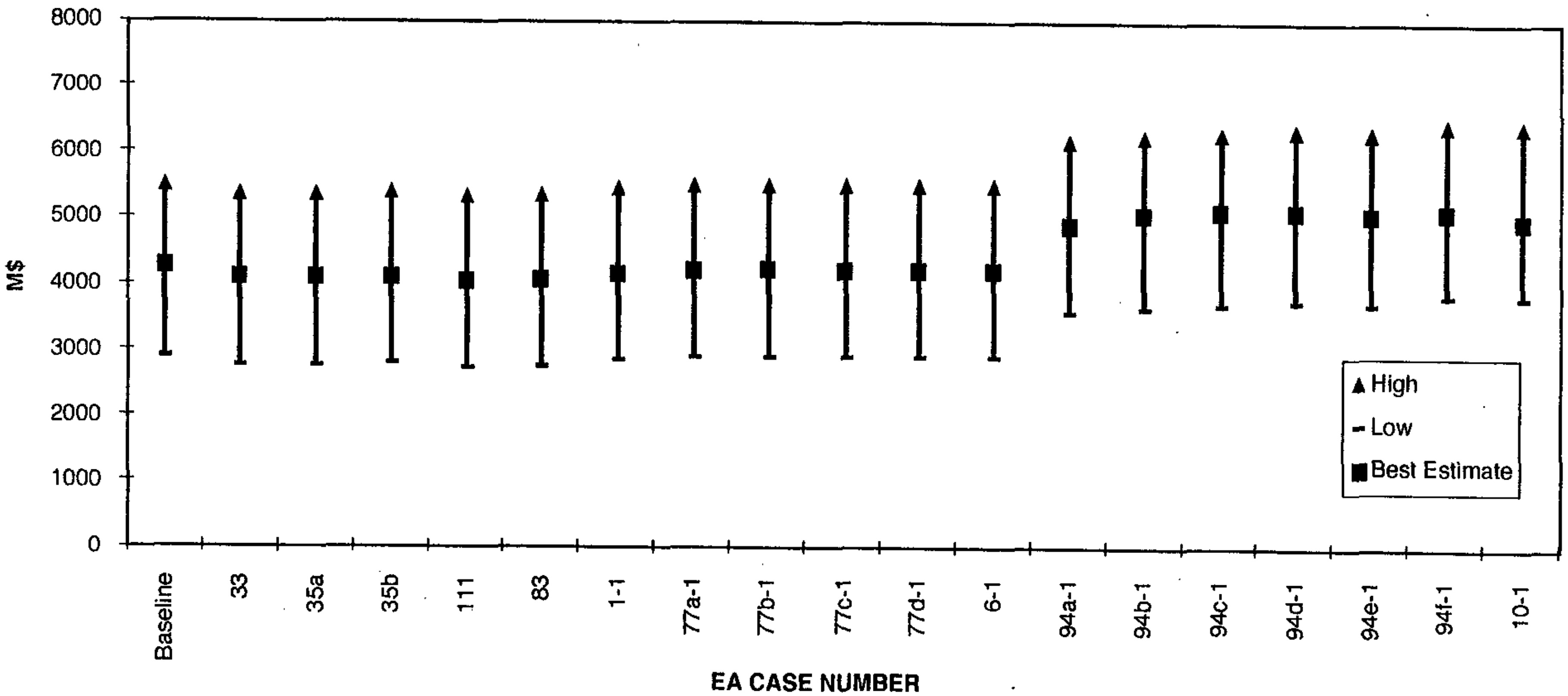

Figure 5-9
Impact of Processing Method on Total TRU Waste System Cost (for Centralized Processing Cases)

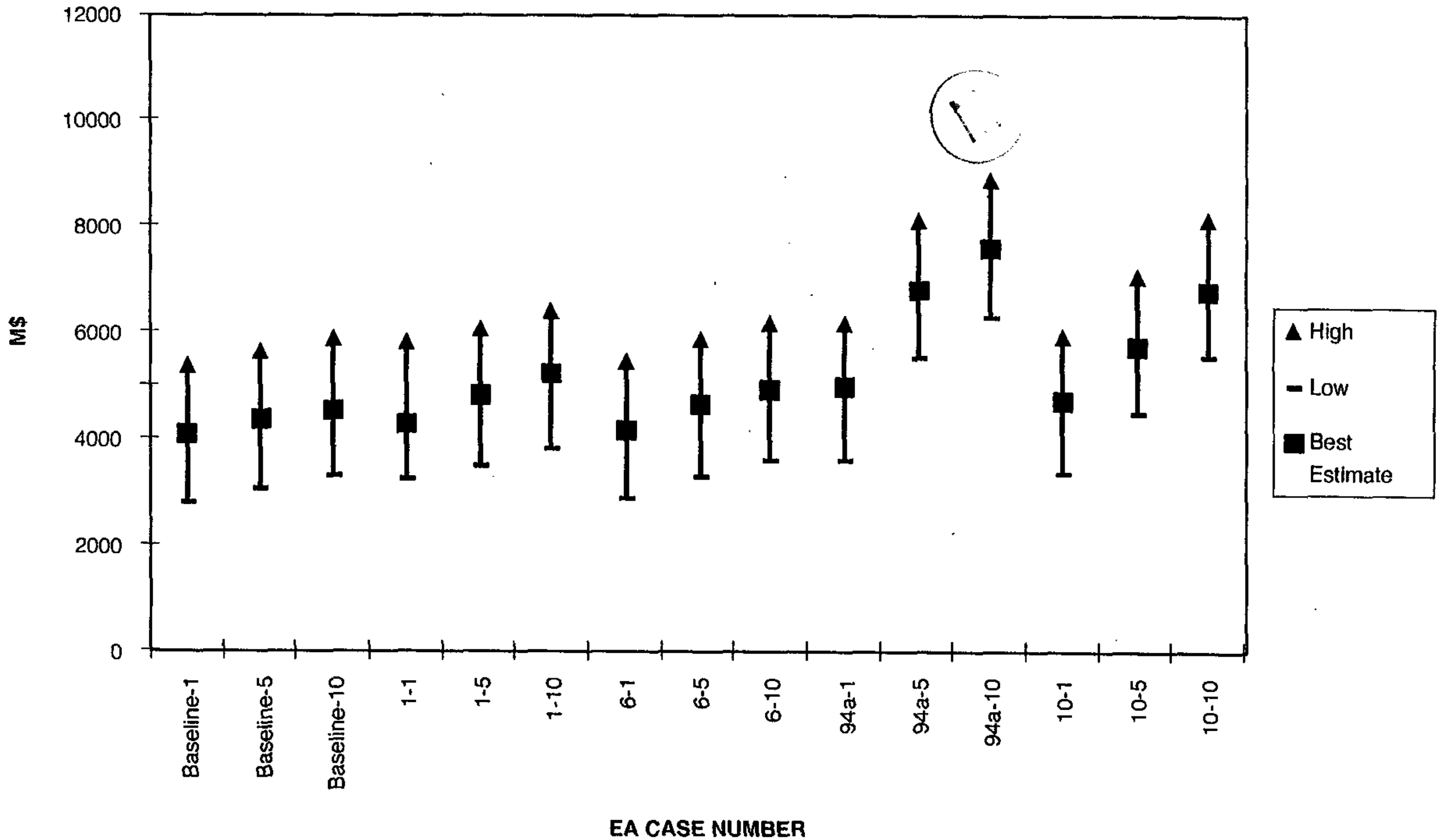

Figure 5-10
Impact Of Processing Location On Total TRU Waste System Cost

Even though the volumes of other waste produced from the TRU program would be increased by processing, the volumes generated were found to be small compared to those coming from other sources. Therefore, the impact on the overall volumes of LLW and LLMW requiring disposal is minor. Thus, the impacts on other waste disposal systems for processing alternatives #1, 6, 77 and 94 are indicated as marginal in Figure 5-3.

5.4.7 WIPP Schedule

Analyses of the potential impacts of EAs on the WIPP operating schedule presented in Chapter 3.7.2 show that the waste processing, placement and backfill activities included in any of the evaluated EAs can be accomplished within a 35 year operational life for WIPP. Underlying this broad conclusion, however, it is also acknowledged that the placement of wastes requiring additional processing may be delayed 12 years or more while the facilities needed to perform the processing are licensed and built. Because of this, the WIPP schedule impacts shown on Figure 5-3 for the first placement of wastes requiring additional processing are indicated to be significantly later than the baseline.

5.4.8 Waste Removal Capability

Table 3-31 summarizes the person-hour effort and associated risks for the hypothetical removal of wastes from WIPP for the baseline and all EAs. This evaluation shows that all EAs except those involving supercompaction of wastes, would require essentially the same effort to remove. EAs that limit the total emplacement volumes below the baseline case (EA#1 and 77 all), reduce the waste removal effort by approximately 50 percent. Thus, EAs 1 and 77a-d are shown as marginally better than the baseline in Figure 5-3.

5.4.9 Public Confidence

Chapter 3.6 documents the potential for selected waste processing and backfill actions to address public concerns expressed about long-term WIPP performance. The evaluated processing and backfill actions were found to have a possible impact on 31% to 42% of the public concerns registered to date. Potential concerns about additional public health risks or TRU disposal system costs prior to WIPP closure have not yet been investigated.

Because of the nature of public opinion and the qualitative analysis used to assess public confidence, measurement of public confidence in the performance of the disposal system was taken as the percentage of comments that could be addressed by an EA. The overall spread of the results were such that they do not lend to differentiation. Therefore, all EAs are indicated as unchanged from the baseline for this impact vector element (Figure 5-3).

5.5 Summary of Observations and Conclusions

Each EA was analyzed in the EACBS and the results are presented in Chapter 3. These results were integrated into a summary presented in Sections 5.1 through 5.4. comparing the results to the baseline. The following sections provide an overview of the limitations of the study and present some observations that were apparent from the evaluation of the results.

Engineered Alternatives analyzed in the EACBS can be categorized into the following three groups.

- Processing Alternatives—Processing alternatives (EA# 1,6 & 10) were analyzed for three processing scenarios, centralized, regionalized and decentralized. The three scenarios have inherent benefits and detriments independent of the EAs. In general, processing alternatives impact the entire waste disposal system, involving the generator/storage sites, waste transportation, other waste disposal systems, and the WIPP waste handling system. Processing alternatives have higher cost, risks and schedule delays than the baseline and backfill only EAs. Processing EAs have a marginal performance impact on the repository excluding plasma processing (EA# 10) which showed a significant increase in repository impact at the expense of having the highest potential risk of all EAs analyzed.

- Backfill Alternatives—Backfill alternatives (EA# 33, 35a, 35b, 83 & 111) have the least impact on the entire waste disposal system. The WIPP waste handling system is impacted; waste transportation, generator/storage sites, and other waste disposal systems are not affected. Cost, schedule radiation and chemical exposure are all similar to the baseline estimates. All backfill alternatives improve long-term disposal system performance.

- Combination Alternatives—Combination alternatives contain both multiple processing and/or backfill alternatives.[1] These alternatives (EA# 77a through 77d and 94a through 94f) have benefits and detriments associated with each alternative type. The overall costs and schedule impacts on the EAs are the highest of all and the transportation, worker and public risks (radiological, chemical accidental and incidental) are also the highest of the alternatives. The overall impact on long-term disposal system performance for combination EAs is comparable to the performance associated with the single backfill and processing alternatives.

5.5.1 Limitations of the Study

- The EAs considered in this study were restricted to waste treatment, backfill, and minor facility design modification such as changes in room dimensions to accommodate treated waste forms. The definition of an EA used in this study does not include processes that would reduce the probability of an intrusive event.

- Assessment of the frequency of human intrusion and any active or passive features that might impact the intrusion frequency were outside the scope of this evaluation. Since any changes affecting the frequency of intrusion would impact both the baseline and each EA equally, those effects cancel when the measures of relative effectiveness are calculated.

- No releases to the accessible environment of radionuclides are predicted to occur under undisturbed performance. Therefore, this analysis focused on EAs that could mitigate the consequences of human intrusion events.

- This study calculated releases to the Culebra; transport processes in the Culebra were not simulated as part of the long-term performance modeling. Since none of

[1] One combination EA contains "Enhanced Cementation of Sludges," a processing EA, that was not one of the individual processing EAs but will be detailed in the Combination EA section.

the EAs evaluated in this study affect those transport processes, the effects of those processes cancel when the measures of relative effectiveness are calculated.

- The actinide sorption properties of clays were not included in the EACBS analysis, impacting the results for EAs that included clay materials. The performance of these EAs may be higher all for radionuclide transport scenarios.

- The cost models used in the EACBS analysis originated in the EMPEIS. The accuracy of the results presented here are a function of the accuracy of the models.

5.5.2 Benefits and Detriments of Processing Alternatives

All EAs involving waste processing were analyzed for three separate scenarios related to where the waste would be processed and how many facilities are to be used. These scenarios have inherent benefits and determents that are independent of the EA. These benefits and determents are discussed below.

5.5.2.1 Centralized Cases

Detriment

The centralized case processes all waste at one processing facility, the WIPP. All generators retrieve, package and certify the waste prior to shipment to the one processing facility. The risks and costs for these operations are the same as baseline, however the overall worker and public risks are higher since all the waste is handled twice, once at the generator and again at the processing facility. Since a majority of the off-site risks are associated with opening of the drums, and the generators and processing facility both perform this operation, the off-site and on-site radiological and health risks are highest for the centralized scenario.

The centralized scenario has the highest potential to impact system wide disposal operations. Since one facility is used to process the waste, it must be fully operational on schedule and must operate as designed without failures. The processing facility is the bottleneck of the disposal system since delays impact the total disposal operation. Success or failure of the centralized processing scenario is dependent on the functional design, siting, permitting, construction, schedule, and functionality of one facility.

WIPP currently has no facilities or capabilities to process the waste. All centralized EAs will require the construction of new facilities to process the waste at WIPP.

Benefit

The centralized scenario has the lowest implementation cost to of the three scenarios (baseline not included). The cost of building one facility will be lower than building five or ten smaller facilities (Figure 5-10). With respect to the baseline, the generator/storage sites incur the same general costs as the baseline, and may be slightly lower. The EACBS assumed that less certification will be required to ship the waste to the processing facility since the shipped waste is not the final waste form emplaced in WIPP. The waste would not need to meet the WIPP WAC, only DOT transportation requirements.

The operational/construction incidental/fatalities are lower than the decentralized scenario and are either better or worse than the regionalized scenario, depending on the particular EA (baseline not included).

All transportation risks are unchanged from the baseline configuration; the transportation scenario for the centralized case is identical to the baseline.

5.5.2.2 Regionalized

Detriments

The regionalized scenario processes waste at five generator sites. The sites are selected such that a majority of the waste is presently stored at those sites, requiring only a small amount of waste to be transported from the other five generator/storage sites. The waste must be retrieved, packaged and certified prior to shipment to the five processing facilities. The five processing sites must also retrieve and handle their waste. Therefore, the total off-site and on-site risks are similar to but slightly higher than the baseline (Table 3-24). This is because the small quantities of waste from the sites shipped to the five processing facilities are handled twice.

For most of the EAs, the cost for the regionalized scenario is significantly higher than the centralized scenario and lower than the decentralized scenario (Figure 5-10). The cost differences between the EAs are due to the current capabilities of the generator storage sites; some sites will require minor modifications to process the waste for the minor processing EAs such as Shred and Compact (#77EAs).

Benefits

The regionalized processing scenario is more flexible than the centralized case. Since five facilities are required, the impact of failure at one facility will not severely impact the total disposal system operations. Failures at sites prior to completion operation of that facility may be overcome by the success of the other facilities; contingencies could include designs that are capable of processing more than would be required for five sites. Schedule impacts and processing rates can be adjusted to compensate for deficiencies at other facilities.

The operational/construction indecent/fatalities are lower than the decentralized scenario and are better or worse than the centralized scenario depending on the particular EA (baseline not included).

Since most of the waste is processed at the five sites, and most processing modifies the waste into a safer form for transportation, a reduction in transportation chemical risk is gained. The radiation risks are assumed to be the same as the baseline except for EAs that reduce the overall waste volume shipped to WIPP.

5.5.2.3 Decentralized

Detriments

The decentralized scenario builds and operates ten processing facilities at the major sites. The cost of this scenario is the highest of all three. The EACBS takes into account the current capabilities of the sites and factors in cost reductions where site capabilities and existing structures for the processing facilities can be utilized. However, not all EAs can utilize current site facilities or capabilities.

The operational/construction indecent/fatalities are generally higher than both the centralized and regionalized scenarios (baseline included).

Benefits

A reduction in the transportation radiation and chemical risks for accident scenarios occurs for most processing EAs because the waste form has been modified. Since all waste is processed prior to shipment to WIPP, all accident scenarios occur with the improved waste form. This reduction is related to the EAs final waste characteristics and is dependent on the particular EA.

5.5.3 Conclusion

The conclusions of this report do not recommend, select or reject EAs based on the results of the EACBS analysis. The results and observations are intended to be used by a DOE decision maker for consideration regarding the potential use of EAs at WIPP for additional assurance. If a decision is made to select an EA for WIPP, it will be made with full system wide knowledge and best available information for which the EACBS provides only a part. The risk cost benefits and overall disposal system impacts must be considered along with the potential benefits if an EA is selected. The EACBS was conceived to provide information regarding these impacts and benefits.

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