Defense Waste Salt Repository - Summary

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel disposition
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SUMMARY

In support of the Department of Energy's (DOE) Management and Disposition Task Force, Savannah River National Laboratory (SRNL) was requested to update the study SRNL-RP-2011-00149, Rev 0, *A Generic Salt Repository for Disposal of Waste from a Spent Nuclear Fuel Recycle Facility* [Carter 2011] to a Defense Waste Repository (DWR) study evaluating disposal of DOE high-level waste and spent nuclear fuel for disposal in a bedded salt geologic setting.

The scope of work [Bushman 2012] requires an executive summary-type report containing the essential findings which is met by this report. A final report is required by May 20, 2012 which will expand upon the bases for the findings described in this report.

Defense Waste Repository Study Scope

The scope of work provided by DOE required that five cases be evaluated as combinations of the disposal inventory and facility location.

Table ES-1 provides the five case numbers resulting from the combinations of the inventory and location cases. The all DOE defense HLW case is evaluated at two locations to evaluate the difference in location for a common inventory while the other three inventory cases are evaluated at a single location.

Table ES-1 Defense Waste Repository Case Matrix

Case Number	SRS HLW	All Defense HLW	All HLW + DOE Spent Fuel	All HLW + DOE and Navy Spent Fuel
WIPP Extension	1	2		
Generic Location		3	4	5

Defense Waste Repository Waste Inventory

Repository waste emplacement footprint is governed by two principle factors, the mine safety considerations for minimum drift spacing and the decay heat areal density limit. The inventory for each Case as a function of waste package decay heat is provided in Table ES-2. The total emplaced decay heat for the total inventory (Case 5) is about 3.6 million watts or about half of the value previously expected. The lower than anticipated decay heat reduces the emplacement footprint underground.

Table ES-2 Defense Waste Repository Waste Canisters Decay Heat Distribution

Decay heat per canister (watts)	**Savannah River Canisters Case 1** Number of canisters	**All DOE HLW Canisters Cases 2 and 3** Number of canisters	**All DOE HLW Canisters and DOE SNF Case 4** Number of canisters	**All Navy Fuel, DOE HLW Canisters and DOE SNF Case 5** Number of canisters
<50	2948	16630	17858	17858
50-100	459	1696	2261	2261
100-220	3891	4414	5203	5203
220-300	0	28	661	661
300-500	264	264	505	505
500-1000	0	0	55	55
1000-1500	0	0	10	10
1500 - 2000	0	0	1	1
>2000	0	0	20	420
Total	**7,562**	**23,032**	**26,574**	**26,974**
Total Decay Heat (watts)	**805,500**	**1,203,100**	**1,901,900**	**3,601,900**

Underground Waste Emplacement Strategy

Evaluation of the defense waste inventory reveals the vast majority of the packages are less than 100 watts each. This allows a much more efficient underground emplacement approach. The team developed an in room disposal approach with variable spacing to accommodate varying waste packages decay heat loads. The minimum spacing selected is 1 foot between canisters (3 feet centerline spacing) to allow for a run-of-mine salt backfill and to ensure packages are not displaced from their intended location as additional waste packages are emplaced. Since all canisters are 2 feet in diameter, except for the naval fuel packages, and mine safety requires a minimum pillar thickness of 100 feet, each waste package is allowed to contain as much as 330 watts assuming the decay heat limit is 10 watts/m^2 (or 0.93 watts/ft^2). The 10 watts/m^2 limit is considered reasonable given that WIPP conducted heater tests during the 1980's at 18 watts/m^2.

A three-dimensional finite-volume heat transfer model has been constructed using the computer code FEHM to investigate the temperatures due to HLW disposal in a generic salt repository. Using a bounding decay heat source term, the maximum temperature projected is around 70-degrees C.

Defense Waste Repository Underground Configuration

The study team developed a panel layout consisting of 10 disposal rooms in each panel. The rooms are 10 ft high by 20 ft wide, and will allow waste emplacement for 500 linear feet each plus an allowance for run-of-mine backfill for shielding at both ends. The panel layout is shown in Figure 4-3 and Table ES-3 estimates the number of rooms and panels required for waste emplacement using the variable spacing for differing waste package decay heat. Table ES-3 also provides the waste emplacement rate and underground emplacement area (rooms and panels) used in this study assuming a 40 year mission life as specified in the study scope of work.

Table ES-3 Waste Emplacement Rooms and Panel Requirements

	Waste Package Spacing (Ft)	SRS HLW Case 1	HLW Waste Packages Cases 2, 3	HLW and SNF Case 4	HLW & SNF & Navy SNF Case 5
	3	44	137	156	156
	4	0	0	0	0
	5	3	3	6	6
	6	0	0	0	0
	8	0	0	0	0
	10	0	0	2	2
	15	0	0	1	1
	20	0	0	1	1
	36	0	0	2	31
	Total Rooms	**47**	**140**	**168**	**197**
	Total Panels	**5**	**14**	**17**	**20**
	Waste Emplacement Rate	189	576	664	674
	Waste Emplacement Rates Rounded	200	675	675	675
	Rooms per year	1.2	3.5	4.2	4.9
	Panels/yr	0.12	0.35	0.42	0.49

Underground and Surface Facilities

Figures 4-4 and 4-5 provides the underground layout for Cases 1, and 2 for the proposed WIPP extension. The configuration is mandated by two key considerations: 1) working around the existing WIPP Defense TRU waste emplacement areas and 2) maintaining a one mile buffer to the land withdrawal act sixteen square mile perimeter.

The existing mine support infrastructure at WIPP is not adequate to support the additional mains and waste emplacement areas. The existing salt shaft is fully utilized by the Defense TRU waste mission and the air intake and exhaust shafts are not adequate to provide the required ventilation for these new drift areas. Therefore both Case 2 and 3 include three new shafts for salt removal, air intake and air exhaust.

Figure 4-3 provides the underground layout for Cases 3, 4 and 5. This generic location layout is more efficient since the 14, 17 or 20 panels required for Cases 3, 4, and 5 respectively can be placed along a linear set of mains. These cases require five access shafts for salt removal, air intake, air exhaust and two waste shafts (see also section 5).

The primary surface facility additions for Case 1 involves addition of a surface lag storage pad for 180 days of processing throughput which is estimated at approximately 100 loaded inbound transportation casks and impact limiters and approximately 50 unloaded outbound casks and impact limiters.

Case 2 processes a much larger inventory of defense waste, involving waste packages of different sizes and weight. The Hanford canisters which comprise almost 50% of the inventory for Cases 2 to 5, are planned to be 15 ft long. Two factors combine to require new remote handled waste facilities at WIPP for Case 2: the increase in defense waste packages from ~200 per year to ~600 per year and 2) the current remote handled waste facility will not accommodate the longer Hanford waste package.

Cases 3 to 5 are located at a generic location and require the full complement of waste receipt, lag storage, waste package handling, and waste package unloading infrastructure for transfer for subsurface emplacement.

Estimated Cost

Table ES-4 provides a summary of the design, construction start-up, operations, closure and monitoring cost (DCSOCMC) range for each of the five cases. These results indicate the cost of disposing of HLW ranges from $13.1 B to $17.9 B in 2012 dollars. This range is established by taking the low from Case 3 (HLW disposed in a generic location) and the high from Case 2 (HLW disposed in a WIPP extension). Although Case 2 is slightly higher than Case 3, the low-high range essentially overlaps indicating there is little cost difference between the two cases. This similarity is driven by the need for new surface facilities to accommodate the larger than WIPP design basis canisters and additional mains to "bypass" the current TRU emplacement area..

The incremental cost of adding the DOE SNF (3,542) canisters to a generic location repository is approximately $120 to 160 million or $34 K to $45 K per canister.

The incremental cost of adding the Naval Fuel to a generic location repository is approximately $1.9 to $2.8 million each. This large difference between the DOE SNF and the Navy SNF is due to the additional repository emplacement area and the additional surface infrastructure requirements. The study team recommends alternative approaches be considered for the Naval Fuel.

A "pilot" Defense Waste Repository which disposes of the SRS only canisters (Case 1) ranges from $8.6 to $11.6B or $1.1 to $1.5M for each canister. The economy of scale can be observed by comparing Cases 1 and Case2 (or3) in which the cost per canister decreases by about half.

Table ES-4 also provides the DCSOCMC in escalated dollars. A centroid of expenditure methodology was utilized to develop escalated cost estimate ranges.

Table ES-4 Design, Construction, Start-up, Operations, Closure and Monitoring Cost Summary

($millions)	**Case 1**		**Case 2**		**Case 3**	
	Low Range	High Range	Low Range	High Range	Low Range	High Range
DCSOCMC	$ 8,550	$ 11,610	$ 13,230	$ 17,930	$ 13,080	$ 17,500
DCSOCMC (including Escalation)	$ 23,860	$ 40,840	$ 36,940	$ 63,050	$ 36,500	$ 61,540
	Case 4		**Case 5**			
DCSOCMC	$ 13,200	$ 17,660	$ 13,990	$ 18,790		
DCSOCMC (including Escalation)	$ 36,830	$ 62,110	$ 39,060	$ 66,070		

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ACRONYMS

DCSOCMC	Design, construction, start-up, operations, closure, and monitoring cost
DOE	Department of Energy
DWPF	Defense Waste Processing facility
DWR	Defense Waste Repository
HIP	high isostatic press
HLW	High Level Waste
LCC	life cycle cost
SNF	Spent Nuclear Fuel
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
TPC	Total Project Cost
TRU	Transuranic
WIPP	Waste Isolation Pilot Plant
WTP	Waste Treatment Plant

USED FUEL DISPOSITION DEFENSE WASTE SALT REPOSITORY- SUMMARY

1. INTRODUCTION

In support of the Department of Energy's (DOE) Management and Disposition Task Force, Savannah River National Laboratory (SRNL) was requested to update the study SRNL-RP-2011-00149, Rev0, *A Generic Salt Repository for Disposal of Waste from a Spent Nuclear Fuel Recycle Facility* [Carter 2011] to a Defense Waste Repository (DWR) study evaluating disposal of DOE high-level waste and spent nuclear fuel for disposal in a bedded salt geologic setting.

The scope of work [Bushman 2012] requires an executive summary-type report containing the essential findings which is met by this report. A final report is required by May 20, 2012 which will expand upon the bases for the findings described in this report.

2. Defense Waste Repository Study Scope

The scope of work provided by DOE required that five cases be evaluated as combinations of the disposal inventory and facility location:

- Four waste inventory cases were evaluated to determine a range of waste emplacement requirements:
    1. Savannah River Site (SRS) Defense Waste Processing Facility (DWPF) borosilicate glass canisters,
    2. all DOE defense High-Level Waste (HLW), comprised of the SRS and Hanford borosilicate glass, and the Idaho calcined/HIPped canisters
    3. all DOE HLW as above plus DOE Spent Nuclear Fuel (SNF) canisters (standard canisters and Hanford Multi-Canister Overpacks)
    4. naval reactor fuel and all DOE HLW and DOE SNF canisters as above
- Two options evaluate disposal location as either an
    1. extension of the Waste Isolation Pilot Plant (WIPP) Facility as constructed or
    2. siting of a new salt repository at a generic or greenfield location

Table 2-1 provides the five case numbers resulting from the combinations of the four inventory cases and two location cases. The all DOE defense HLW case is evaluated at two locations to evaluate the difference in location for a common inventory while the other three inventory cases are evaluated at a single location.

Table 2-1 Defense Waste Repository Case Matrix

Case Number	SRS HLW	All HLW	All HLW + DOE Spent Fuel	All HLW + DOE and Navy Spent Fuel
Location				
WIPP Extension	1	2		
Generic Location		3	4	5

3. Defense Waste Repository Inventory

Repository waste emplacement footprint is governed by two principle factors, the mine safety considerations for minimum drift spacing and the decay heat areal density limitations. The inventory for each of the four inventory scenarios as a function of waste package decay heat is provided below.

3.1 SRS Borosilicate Glass Canister Inventory – Case 1

SRS began conversion of the liquid defense waste into borosilicate glass in 1996 and is the only DOE site with HLW in a packaged configuration. A total of 3325 canisters have been produced through December, 2011. Therefore, the SRS inventory can be described as those canisters in the current inventory and those projected from future operations. Decay heat of the current inventory is based on radiological inventories contained in the production records for those canisters. The decay heat of future canisters is estimated based on radionuclide inventory of the inventory of HLW remaining in the liquid waste storage tanks. The radionuclide and resulting decay heat was calculated based on the year the canister is/will be produced. The total Savannah River canister count is based in information supporting Savannah River Liquid Waste Disposition Plan revision 16.

Table 3-1 provides the canister distribution of SRS canisters based on the nominal decay heat at the time of production. The data indicates: 39% of the Savannah River canisters will be less than 50 watts; 96% of the Savannah River canisters will be less than 300 watts; all the SRS canisters will be less than 500 watts.

Table 3-1 Savannah River Canister Decay Heat Distribution

	Savannah River	
Decay heat per canister (watts)	Number of canisters	Cumulative %
<50	2948	39.0%
50-100	459	45.1%
100-220	3891	96.5%
220-300	0	96.5%
300-500	264	100.0%
500-1000	0	100.0%
1000-1500	0	100.0%
1500 - 2000	0	100.0%
>2000	0	100.0%
Total	**7,562**	
Total Decay Heat (watts)	**805,500**	

3.2 DOE HLW Inventory – Case 2 and 3

Case 2 and 3, which differ in location, share a common inventory. This inventory includes the SRS and Hanford Borosilicate glasses and the Idaho calcine canisters.

3.2.1 Hanford Borosilicate Glass Canisters

The Hanford Waste Treatment Project (WTP) is currently under construction and therefore the Hanford borosilicate glass canisters are based on a projected inventory for their future production taken from the January 2011 Waste Treatment Plant document titled "2010 Tank Utilization Assessment". The data in Table 3-2 indicates: 83% of the Hanford canisters will be less than 50 watts; and 100% of the Hanford canisters will be less than 300 watts.

3.2.2 Idaho Calcine Waste Canisters

Decay heat of DOE HLW that has been calcined and is currently stored at the Idaho site is taken from the October 2005 Idaho Cleanup Project document titled "Decay Heat and Radiation from Direct Disposed Calcine", EDF-6258 revision 0. Report EDF-6258 provides this data for direct disposal of the calcine waste. The current Record of Decision for disposal of the calcine is for it to be treated using a hot isostatic pressing (HIP), which will result in an approximate 50% increase in the volume of material in each disposal canister and an 50% increase in the decay heat per canister.

Table 3-2 provides the distribution of DOE calcine canisters based on the nominal decay heat in the year 2016. The data indicates that 100% of calcine canisters will be less than 50 watts.

Table 3-2 Hanford and Idaho waste Inventory

	Hanford Borosilicate Glass		**Idaho Calcine**	
Decay heat per canister (watts)	Number of canisters	Cumulative %	Number of canisters	Cumulative %
<50	9291	83.9%	4391	100.0%
50-100	1237	95.0%		
100-220	523	99.7%		
220-300	28	100.0%		
300-500	0	100.0%		
500-1000	0	100.0%		
1000-1500	0	100.0%		
1500 - 2000	0	100.0%		
>2000	0	100.0%		
Total	**11,079**		**4391**	

3.2.3 Case 2 and 3 Inventory from SRS, Hanford and Idaho

The combined inventory from all three sites, which is used in Cases 2 and 3 is presented in Table 3-3. The data indicates: 72% of the HLW canisters will be less than 50 watts; ~80% of the canisters will be less than 100 watts; almost 99% will be less than 300 watts and all the canisters will be less than 500 watts. The total decay heat to be emplaced in these cases is 1.2 million watts.

Table 3-3 Case 2 and 3 Inventory of All DOE HLW

Decay heat per canister (watts)	**All DOE HLW Canisters** Number of canisters	Cumulative %
<50	16630	72.2%
50-100	1696	79.6%
100-220	4414	98.7%
220-300	28	98.9%
300-500	264	100.0%
500-1000	0	100.0%
1000-1500	0	100.0%
1500 - 2000	0	100.0%
>2000	0	100.0%
Total	**23,032**	
Total Decay Heat (watts)	**1,203,103**	

Not included in Table 3-3 are a) 275 HLW canisters from West Valley which have low heat values, and b) the Idaho HLW to be processed through the Integrated Waste Treatment Unit and then per the associated Record of Decision will be disposed of as RH-TRU.

3.3 Spent Nuclear Fuel and HLW Inventory- Case 4

Decay heat of DOE Spent Nuclear Fuel (SNF) is based on the estimated radionuclide inventory. In support of the Yucca Mountain License Application, an analytical process using process knowledge and the best available information regarding fuel fabrication, operations, and storage for DOE SNF was used to develop a conservative radionuclide inventory estimate. This methodology was applied to each fuel in the DOE SNF inventory to develop a radionuclide estimate. Also in support of the Yucca Mountain License Application, a packaging plan was developed using the DOE standardized canisters. These two data sources are used to estimate the decay heat per canister for DOE SNF.

The radionuclide and resulting decay heat was calculated in the year 2010 and 2030 to support the Yucca Mountain repository. Considering the time required before a repository for DOE SNF would be open to accept waste, these values are considered adequate for this scoping evaluation.

Table 3-4 provides the distribution of DOE SNF canisters based on the 2010 and 2030 nominal decay heat using the 2035 total canister count. The 2010 data indicates approximately 35% of the DOE SNF canisters will be less than 50 watts. Approximately 90% of the DOE SNF canisters will be less than 300 watts. Nearly all the DOE SNF canisters (>99%) will be less than 1 kW. Since the methodology used to calculate the radionuclide inventory is very conservative, some fuels have radionuclide amounts based on bounding assumptions resulting in extreme decay heat values.

Table 3-4 DOE Spent Nuclear Fuel Canister Decay Heat

	2010		2030	
Decay heat per canister (watts)	Number of canisters	Cumulative %	Number of canisters	Cumulative %
<50	1228	34.7%	1670	47.1%
50-100	565	50.6%	392	58.2%
100-220	789	72.9%	690	77.7%
220-300	633	90.8%	586	94.2%
300-500	241	97.6%	140	98.2%
500-1000	55	99.1%	41	99.4%
1000-1500	10	99.4%	4	99.5%
1500 - 2000	1	99.4%	5	99.6%
>2000	20	100.0%	13	100.0%
Total	**3542**		**3542**	

Does not include the Savannah River Site SRE fuel

Table 3-5 provides the combined HLW and SNF inventory data for Case 4. The total emplaced decay heat for this case is about 1.9 million watts.

Table 3-5 DOE HLW and SNF for Case 4

	All DOE HLW Canisters and DOE SNF	
Decay heat per canister (watts)	Number of canisters	Cumulative %
<50	17858	67.2%
50-100	2261	75.7%
100-220	5203	95.3%
220-300	661	97.8%
300-500	505	99.7%
500-1000	55	99.9%
1000-1500	10	99.9%
1500 - 2000	1	99.9%
>2000	20	100.0%
Total	**26,574**	
Total Decay Heat (watts)	**1,901,928**	

3.4 Naval Reactor Fuel, DOE Spent Nuclear Fuel and HLW Inventory-Case 5

Naval reactor fuel is packaged in 400 containers, 310 are long canisters (212”) and 90 are short canisters (187”). Each has a maximum diameter of 66.5” and a design weight of 98,000 lbs including the contents. The average thermal load is 4,250 watts/container. Maximum is 11, 800 watts/container.

Table 3-6 provides the combined Navy SNF, DOE SNF and DOE HLW for Case 5. The total emplaced decay heat for this case is about 3.6 million watts or about half of the value previously expected. The lower than anticipated decay heat reduces the emplacement footprint underground.

Table 3-6 Navy and DOE SNF and DOE HLW for Case 5

	All Navy Fuel, DOE HLW Canisters and DOE SNF	
Decay heat per canister (watts)	Number of canisters	Cumulative %
<50	17858	66.2%
50-100	2261	74.6%
100-220	5203	93.9%
220-300	661	96.3%
300-500	505	98.2%
500-1000	55	98.4%
1000-1500	10	98.4%
1500 - 2000	1	98.4%
>2000	420	100.0%
Total	**26,974**	
Total Decay Heat (watts)	**3,601,928**	

4. Underground Waste Emplacement Strategy

The mining layout was developed on the basis of thermal load and mining experience. The waste emplacement approach was altered from the prior Commercial SNF reprocessing waste study in which one HLW canister was emplaced per alcove. To maintain the areal thermal limit of 39 watts/m^2 these alcoves were on a 40 foot square array. The canister was to be placed on the floor in the alcove and covered with at least 10 feet of mined salt to provide shielding between the canister and the room.

Evaluation of the defense waste inventory reveals the vast majority of the packages are less than 100 watts each. This allows a much more efficient underground emplacement approach. The team developed an in room disposal approach with variable spacing to accommodate waste packages with higher heat loads. The minimum spacing selected is 1 foot between canisters (3 feet centerline spacing) to allow for a run-of-mine salt backfill and to ensure packages are not displaced from their intended location as additional waste packages are emplaced. Since all canisters are 2 feet in diameter, except for the naval fuel packages, and mine safety requires a minimum pillar thickness of 100 feet, each waste package is allowed to contain as much as 330 watts assuming the decay heat limit is 10 watts/m^2 (or 0.93 watts/ft^2). The 10 watts/m^2 limit is considered reasonable given that WIPP conducted heater tests during the 1980's at 18 watts/m^2.

4.1 Thermal Modeling

A three-dimensional finite-volume heat transfer model has been constructed using the computer code FEHM to investigate the temperatures due to HLW disposal in a generic salt repository. The model has been constructed in a manner to facilitate modification as the study progresses. It is designed as an interior room within a panel. Due to the symmetry of the room, the model is limited to one side of the room, extending halfway to the center of the next room. Temperature influences from the missing half of the room and adjacent rooms is considered using reflection boundaries along the sides of the model. Access drifts at both ends of the room are included to their centers where reflection boundaries have been imposed. Figure 4-1 presents the model layout.

The current model uses an orthogonal grid with refinement within and near the room, expanding geometrically to the boundaries. Grid generation is automated to facilitate modifications to the canister dimensions and spacing, room dimensions and spacing, etc. An initial model run has been performed assuming approximately 2-foot diameter by 10 foot long canisters placed crosswise in an approximately 10-foot high by 20-foot wide by 600-foot long room. The canisters are placed with approximately 1-foot in between them (3-foot between canister centers). It is assumed that the salt is back-filled over the canisters to a depth of 4-feet tapering at the ends with approximately 25-degree angles. The heat load in each canister is assumed to be 220 W. Figure 4-2 presents the temperatures after 200 years, where the top half of the model is cut out so that the temperatures along the centers of the canisters can be viewed. It is apparent that the maximum temperature is around 70-degrees C.

The design optimization, parameter estimation, uncertainty quantification, and sensitivity analysis code DAKOTA (Adams et al. 2011) has been configured to perform parallel executions of the model. A python code has been written to allow DAKOTA to investigate model parameters and configurations. As mentioned above, the model has been constructed to facilitate these parameter and configuration investigations. A preliminary multi-dimensional parameter study has been conducted investigating the canister spacing and canister heat load on the maximum temperature on an early model configuration. This framework (i.e. FEHM simulator, python code, and DAKOTA) is now being used to perform various multi-dimensional parameter studies, design of computer experiments, uncertainty analyses, and sensitivity analyses to investigate the effect of canister spacing, canister heat load, depth of salt backfill, room spacing, uncertainty in thermal properties of intact and crushed salt, etc. on temperatures. This framework will provide step-wise guidance in the iterative design of a generic HLW salt repository.

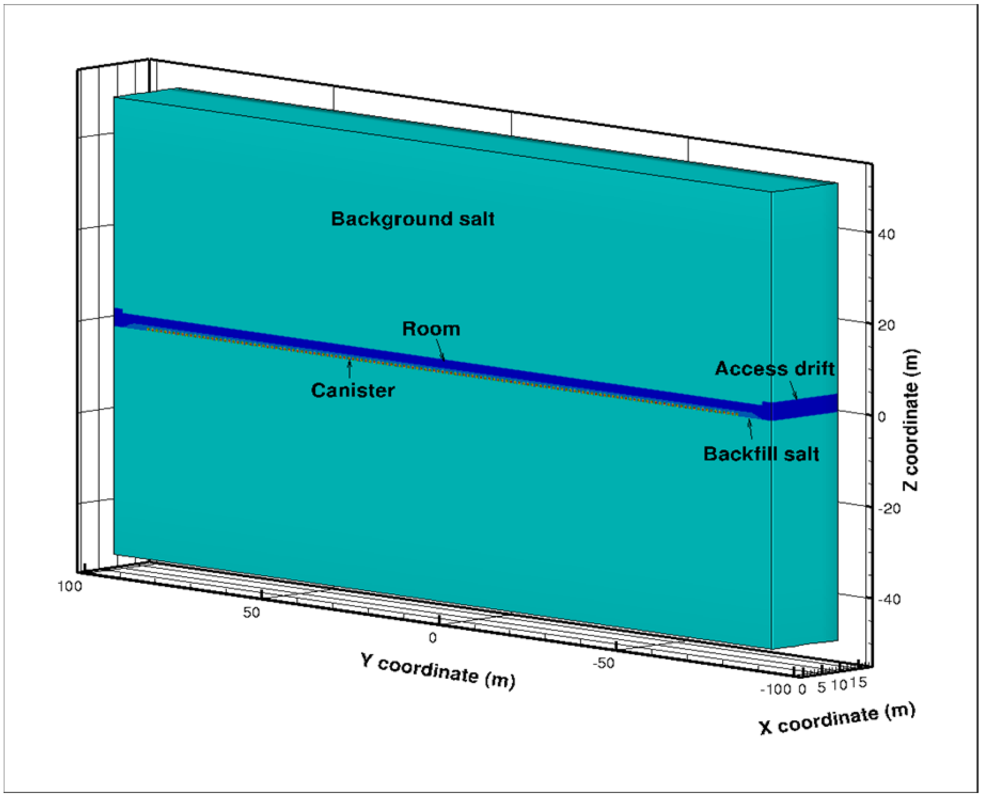

Figure 4-1. Heat transfer model layout.

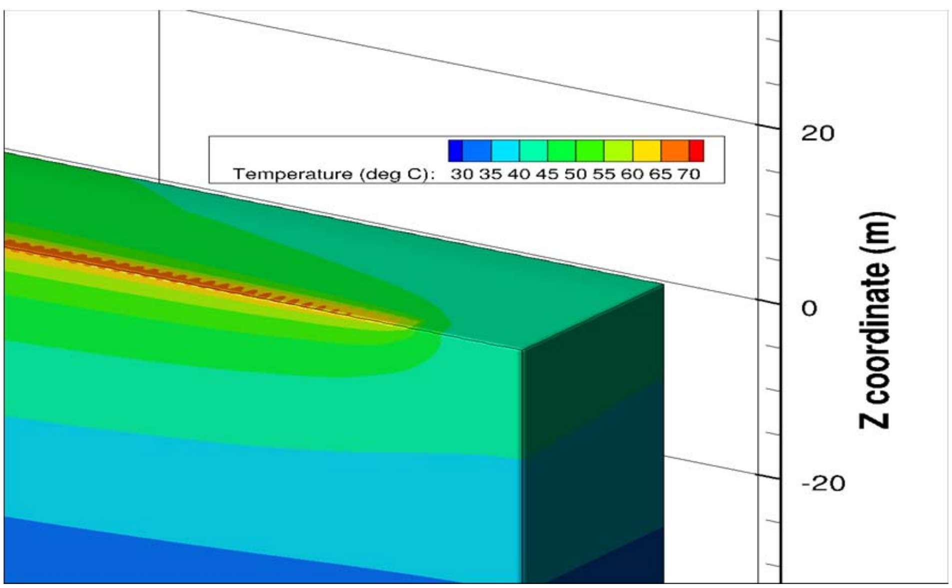

Figure 4-2. Temperature after 200 years with 220 W canisters. Upper part of model is cut out to view the center of the canisters.

4.2 Defense Waste Repository Underground Configuration

Table 4-1 provides the waste package distribution as a function of decay heat and linear spacing for each of the five cases.

Table 4-1 Defense Waste Package Spacing Distribution

Spacing Between Packages	Allowable Decay Heat (watts/package)	SRS HLW Case 1	HLW Waste Packages Cases 2, 3	HLW and SNF Case 4	HLW & SNF & Navy Case 5
3	330	7298	22768	25983	25983
4	450	0	0	0	0
5	560	264	264	505	505
6	670	0	0	0	0
8	900	0	0	0	0
10	1100	0	0	55	55
15	1700	0	0	10	10
20	2200	0	0	1	1
36	4000	0	0	20	420

The study team developed a panel layout consisting of 10 disposal rooms in each panel. The rooms are 10 ft high by 20 ft wide, and will allow waste emplacement for 500 linear feet each plus an allowance for run-of-mine backfill for shielding at both ends. The panel layout is shown in Figure 4-3 and Table 4-2 estimates the number of rooms and panels required for waste emplacement using the variable spacing in Table 4-1. Table 4-2 also provides the waste emplacement rate and underground emplacement area (rooms and panels) used in this study assuming a 40 year mission life as specified in the study scope of work.

Table 4-2 Waste Emplacement Rooms and Panel Requirements

Waste Package Spacing (Ft)	SRS HLW Case 1	HLW Waste Packages Cases 2, 3	HLW and SNF Case 4	HLW & SNF & Navy SNF Case 5
3	44	137	156	156
4	0	0	0	0
5	3	3	6	6
6	0	0	0	0
8	0	0	0	0
10	0	0	2	2
15	0	0	1	1
20	0	0	1	1
36	0	0	2	31
Total Rooms	**47**	**140**	**168**	**197**
Total Panels	**5**	**14**	**17**	**20**
Waste Emplacement Rate	189	576	664	674
Waste Emplacement Rates Rounded	200	675	675	675
Rooms per year	1.2	3.5	4.2	4.9
Panels/yr	0.12	0.35	0.42	0.49

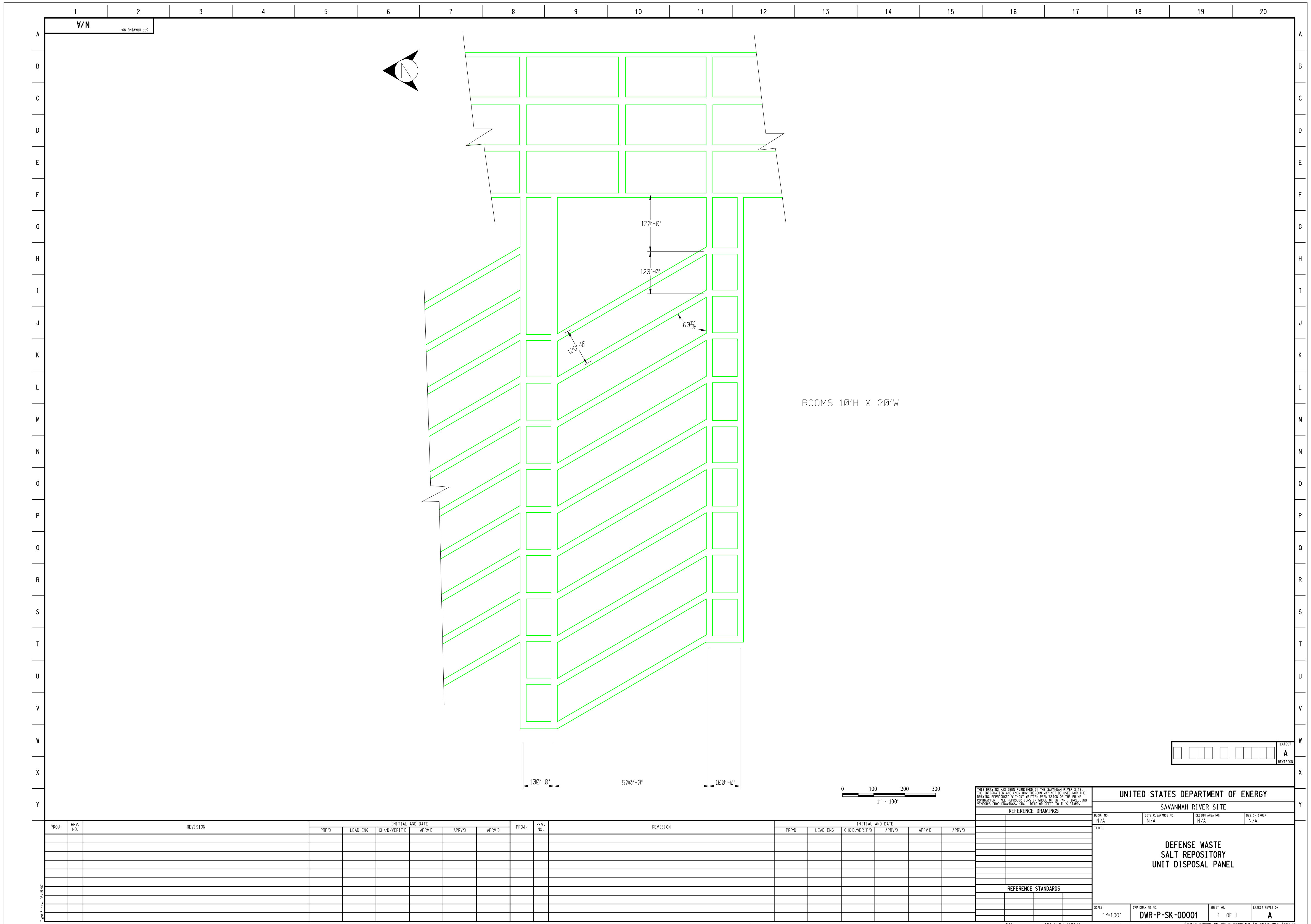

Figure 4-3 Disposal Panel Configuration

Figures 4-4 and 4-5 provides the underground layout for Cases 1, and 2 for the proposed WIPP extension. The configuration is mandated by two key considerations: 1) working around the existing WIPP Defense TRU waste emplacement areas and 2) maintaining a one mile buffer to the land withdrawal act sixteen square mile perimeter.

For Case 1, this configuration requires a set of four "U" shaped access mains to connect the current shaft pillar area to the south side of the current emplacement mains. The five waste emplacement panels are to the west side of these access mains. To accommodate the 14 panels required for Case 3, a second set of "U" shaped access mains is proposed on the east side of the current emplacement panels. Figure 4-5 has 17 panels to indicate the waste emplacement area is adequate for more waste than strictly required for Case 2 (14 panels). These long "U" shaped access panels contribute significantly to the Total Project Cost (TPC) as the west side mains are required to be completed as part of the initial construction. The west side mains are assumed to be constructed while the first five panels are being filled and are included in the Life Cycle Cost (LCC) estimate for Case 2.

The existing mine support infrastructure at WIPP is not adequate to support the additional mains and waste emplacement areas. The existing salt shaft is fully utilized by the Defense TRU waste mission and the air intake and exhaust shafts are not adequate to provide the required ventilation for these new drift areas. Therefore both Case 2 and 3 include three new shafts for salt removal, air intake and air exhaust.

The existing WIPP waste emplacement shaft is judged to be adequate for Case 1 in which 200 packages per year are required to be emplaced assuming a second shift operation at WIPP. However, a single waste shaft is not adequate for Case 2 in which nearly 600 waste packages per year need to be emplaced. The scope for Case 2 includes a new waste shaft.

Figure 4-3 provides the underground layout for Cases 3, 4 and 5. This generic location layout is more efficient since the 14, 17 or 20 panels required for Cases 3, 4, and 5 respectively can be placed along a linear set of mains. These cases require five access shafts for salt removal, air intake, air exhaust and two waste shafts (see also section 5).

Underground openings are constructed using readily available mining equipment. Opening dimensions are selected to minimize the amount of mining needed. A continuous mining machine will cut an opening 11 ft wide by 10 ft high in a single pass. The room dimensions are 10 ft high by 20 ft wide to accommodate waste packages up to 15 ft long and provide an allowance for the shielded conveyance.

Entries and haulage ways are mined taller and wider than disposal areas in order to accommodate the orderly flow of underground traffic and to accommodate the larger vehicles needed to support mining and waste emplacement. These are 20 feet high by 30 feet wide and require two vertical and three horizontal passes to mine. Adjustment to these dimensions may be made once a specific location (depth and salt horizon properties) has been established. Table 4-3 provides the linear feet of drifts for each case.

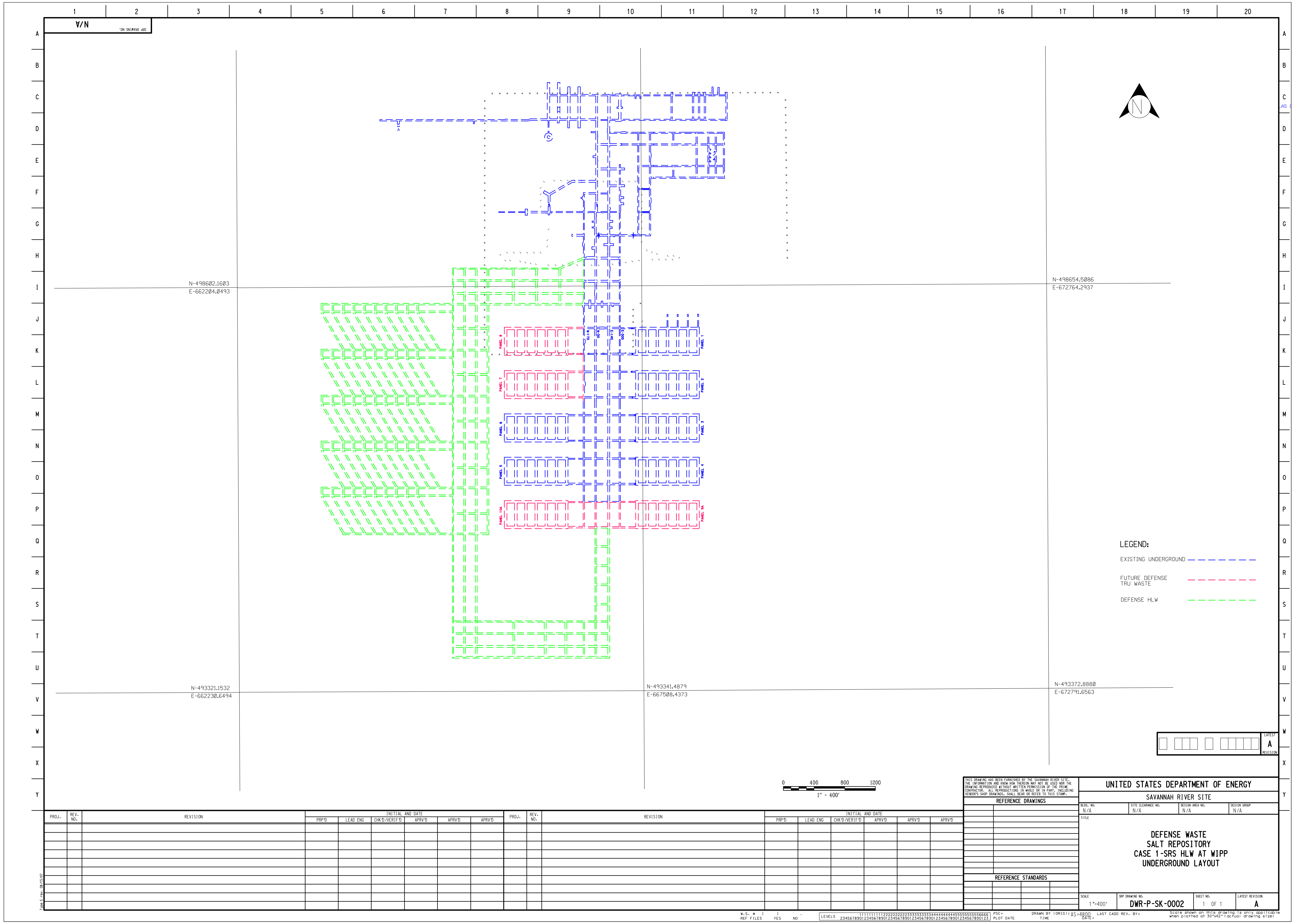

Figure 4-4 Case 1 SRS Waste at WIPP Underground Repository Plot Plan

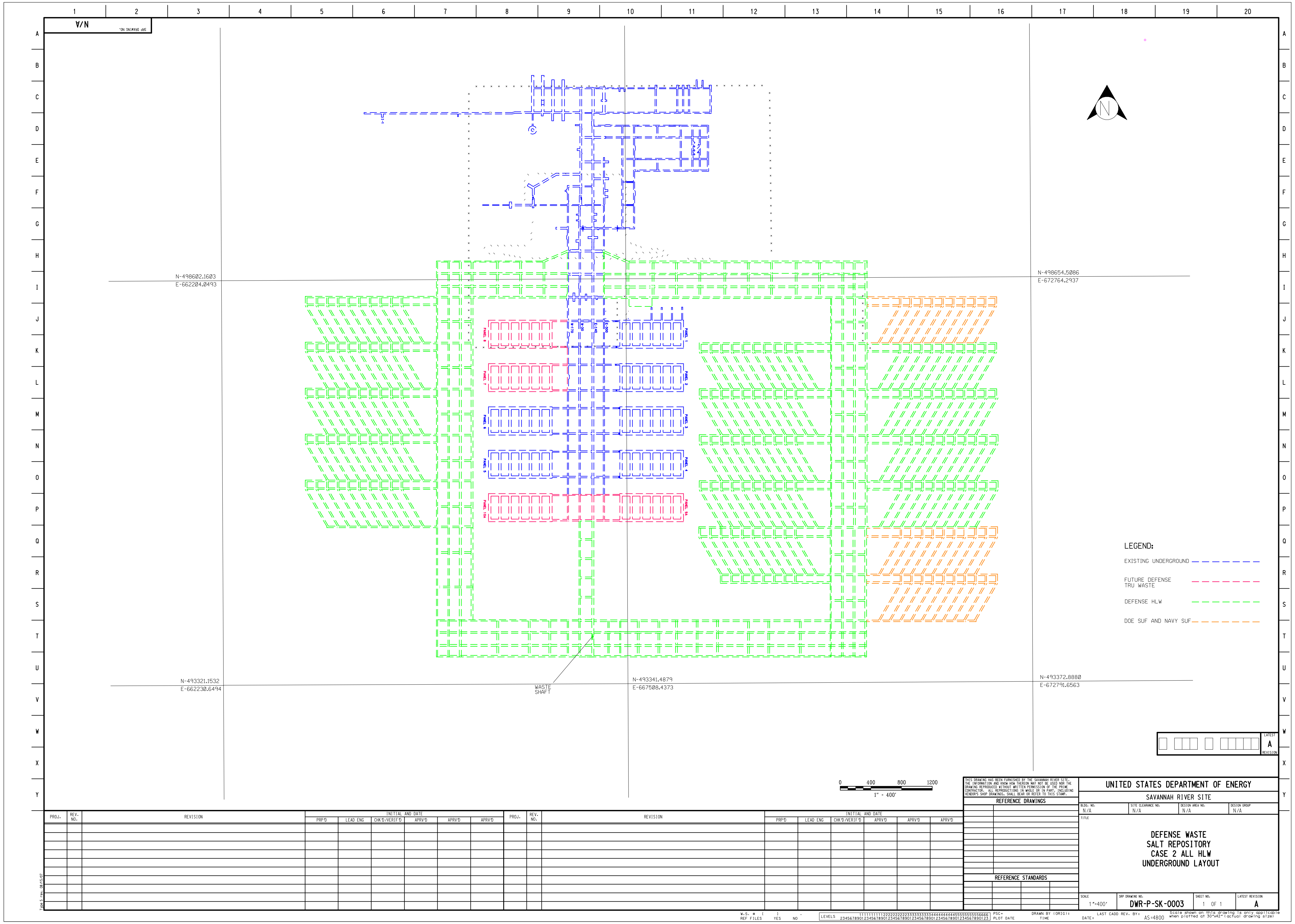

Figure 4-5 Case 2 All Defense Waste at WIPP Underground Repository Plot Plan

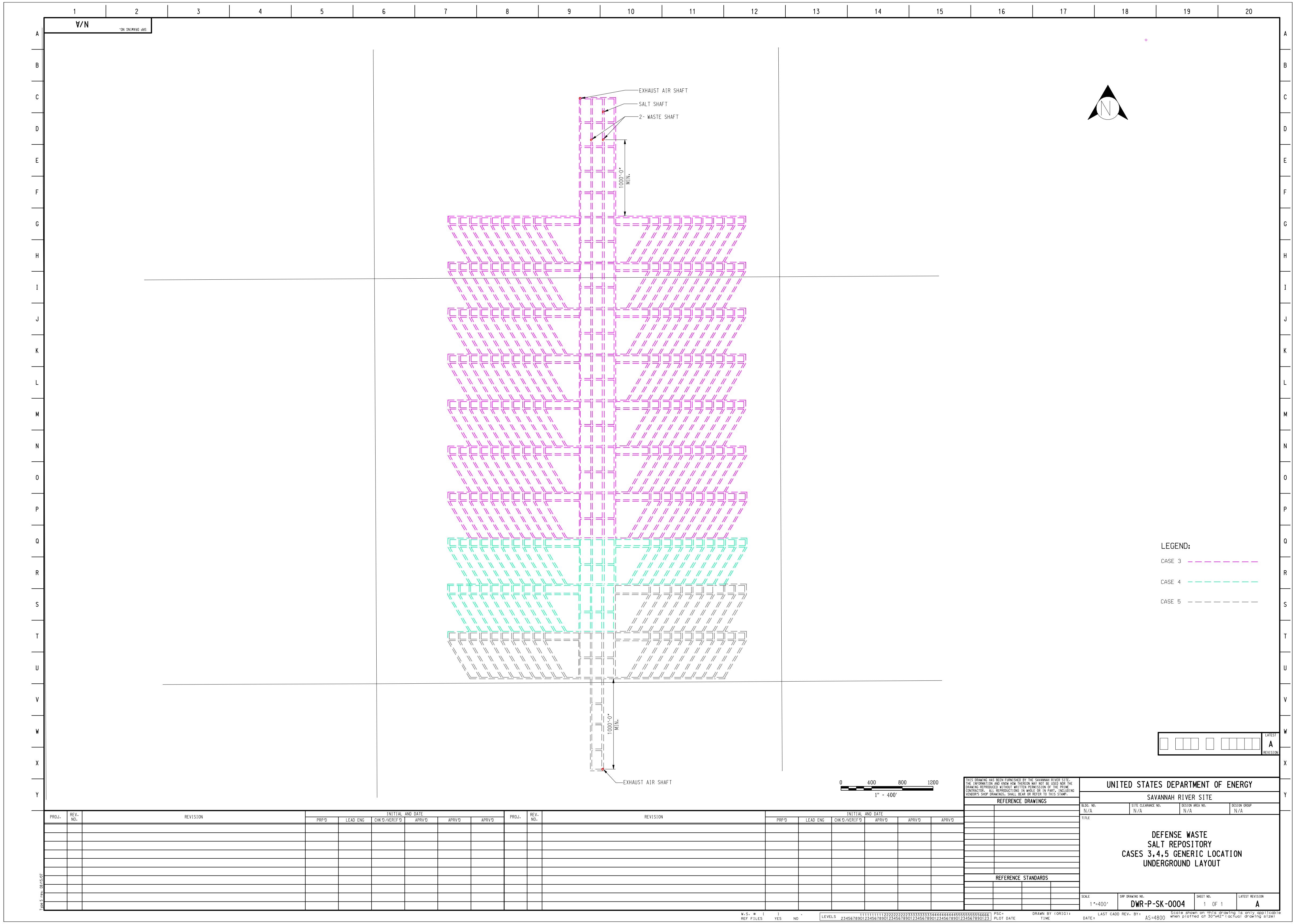

Figure 4-6 Case 3, 4 and 5 All Defense Waste at a Generic Location Underground Repository Plot Plan

Table 4-3 Emplacement Drift Single Pass Mining Length

		Case 1	Case 2	Case 3	Case 4	Case 5
Total Mains	**Lin Ft**	**270600**	**644700**	**251400**	**251400**	**251400**
TPC	Lin Ft	270600	270600	251400	251400	251400
LCC	Lin Ft		374100			
Total Panels	**Lin Ft**	**151000**	**422800**	**422800**	**513400**	**604000**
TPC	Lin Ft	24200	30200	30200	30200	30200
LCC	Lin Ft	126800	392600	392600	483200	573800
Annual in LCC	Lin Ft	3200	9800	9800	12100	14300
Grand Total	**Lin Ft**	**421,600**	**1,067,500**	**674,200**	**764,800**	**855,400**

Based on experience with mining salt in the United Sates and with WIPP specifically, a mining rate for 40 feet per day per mining machine is a reasonable assumption. The crew size required to support each mining machine is then used to establish the cost of the mining operations.

5. Surface Support Facilities

Surface facilities for the DWR are developed for the five cases ranging from Case 1, with WIPP existing surface facilities providing the majority of surface infrastructure needed to emplace the ~7600 SRS canisters over the DWR mission life with very limited additional surface facility additions, to Cases 2 through 5 which provide additional surface infrastructure in order to handle additional inventory.

The primary surface facility additions for Case 1 involves addition of a surface lag storage pad for 180 days of processing throughput which is estimated at approximately 100 loaded inbound transportation casks and impact limiters and approximately 50 unloaded outbound casks and impact limiters. Approximately 8.25 acres and one cask shuttle crane crawler is assigned for this lag storage, outside and east of the current WIPP facility footprint. The new air intake and air exhaust shaft will be provided south of the current mission footprint complete with attendant surface infrastructure including exhaust filter building, air intake shaft hoist building, air intake shaft winch building, exhaust shaft monitoring station, air intake shaft head frame, salt handling shaft hoist building, salt handling shaft operations building, salt handling shaft head frame and tailings vehicle shelter. This surface infrastructure will be located approximately one mile south of the current WIPP facility surface facilities.

Case 2 processes a much larger inventory of defense waste, involving waste packages of different sizes and weight. The Hanford canisters which comprise almost 50% of the inventory for Cases 2 to 5, are planned to be 15 ft long. Two factors combine to require new remote handled waste facilities at WIPP for Case 2: The increase in Defense waste packages from ~200 per year to ~600 per year and 2) the current remote handled waste facility will not accommodate the longer waste.

Case 3 to 5 are located at a generic location and require the full complement of waste receipt, lag storage, waste package handling, and waste package unloading infrastructure for transfer for subsurface emplacement.

The surface facility for Case 2 to 5 will be equipped with the following principle infrastructure features: similar air supply & air exhaust and salt handling surface facilities would be included as for Case 1. Two 50 ton capacity waste hoists would be added for Cases 3-4 and one 50 ton capacity waste hoist and one 400 ton capacity waste hoist would be provided for Case 5. The larger capacity hoist would be needed for Case 5 to handle the much larger naval fuel waste packages. A 400 ton capacity 2000 foot hoist is beyond current mining industry capabilities which appear to be limited to ~250 tons. The design construction and operations of this hoist is a high risk potential item and the team recommends other options be considered such as repackaging the Naval Fuel Canisters into smaller packages that could readily be accommodated by industry standard shaft access hoists.

Larger rail and truck receipt capability would be provided together with a larger lag storage area, on the order of 24 acres, for loaded inbound transportation casks & impact limiters and unloaded outbound casks & impact limiters. The receipt facility would support package receipt and transfer to the underground through one new waste unloading area and waste shaft transfer path for Case 2 and two waste unloading areas & waste shaft transfer paths for Cases 3-5.

Table 5-1 summarizes key surface facility infrastructure differences for the five cases.

Table 5-1 Facility Listing for All Cases

ID	Facility	Case 1	Case 2	Case 3	Case 3	Case 4	Case 5
SF102-RH	102-RH		✓	✓	✓	✓	✓
SF102HC	102HC		✓	✓	✓	✓	✓
SF109	109 - Rail Staging		✓	✓	✓	✓	✓
SF110	110 - Truck Staging		✓	✓	✓	✓	✓
SF600	Low Level Waste (LLW) Facility {600}			✓	✓	✓	✓
SF700A	Central Control Facility { 700A}		✓	✓	✓	✓	✓
SF107	Waste Handling Maintenance Bldg 107		✓	✓	✓	✓	✓
SF108	Cont. Equipment Maintenance Facility 108		✓	✓	✓	✓	✓
SF1005	Heavy Equipment Maintenance Facility {10		✓	✓	✓	✓	✓
SF1000	Warehouse & Central Receiving {1000}			✓	✓	✓	✓
SF500	Analytical Support Facility {500}			✓	✓	✓	✓
SF816	Emergency Diesel Generator Facility { 81	✓	✓	✓	✓	✓	✓
SF802	Compressor Building {802}	✓	✓	✓	✓	✓	✓
SF803	Chilled Water Services and Cooling Tower	✓	✓	✓	✓	✓	✓
SF809	Evaporation Pond(s) {809}	✓	✓	✓	✓	✓	✓
SF810	Standby Diesel Generator Facility { 810	✓	✓	✓	✓	✓	✓
SF1004	Fuel & Diesel Oil Storage and Fueling St	✓	✓	✓	✓	✓	✓
SF812	Switchyard (Offsite power) {812}		✓	✓	✓	✓	✓
SF813	Offsite Power Switchgear Facility {813}		✓	✓	✓	✓	✓
SF815	Fire Water Facility {815-E and 815-W}		✓	✓	✓	✓	✓
SF700B	Central Security Station {700B}		✓	✓	✓	✓	✓
SF705	Package Receipt Security Station {705}		✓	✓	✓	✓	✓
SF808	Stormwater Retention Pond {808}		✓	✓	✓	✓	✓
SF1001	Central Maintenance and Craft Shops {100		✓	✓	✓	✓	✓
SF202	Exhaust filter building {202}	✓	✓	✓	✓	✓	✓
SF817	Salt and Excavated Rock Tailings Surfac	✓	✓	✓	✓	✓	✓
SF701	Emergency Response & Medical {701} (3 I		✓	✓	✓	✓	✓
SF703	Entry Control Facilities {703}		✓	✓	✓	✓	✓
SF704	Gate House {704}		✓	✓	✓	✓	✓
SF1003	Equipment and Materials/Yard Storage {1		✓	✓	✓	✓	✓
SF900	Central Engineering and Administration F		✓	✓	✓	✓	✓
SF1006	Vehicle Maintenance & Motor Pool {1006}		✓	✓	✓	✓	✓
SF	Parking		✓	✓	✓	✓	✓
SF	Paved Roads		✓	✓	✓	✓	✓
SF	Gravel Roads		✓	✓	✓	✓	✓
SF	Railroads	✓	✓	✓	✓	✓	✓

✓ = Infrastructure provided in addition to WIPP as applicable to case scope.

Table 5-1 (Continued)

ID	Facility	Case 1	Case 2	Case 3	Case 3	Case 4	Case 5
SF804	Potable and non-potable water systems {		✓	✓	✓	✓	✓
SF805	Sanitary Waste Treatment {805}		✓	✓	✓	✓	✓
SF806	Grey Water Pond 1 {806}		✓	✓	✓	✓	✓
SF807	Grey Water Pond 2 {807}		✓	✓	✓	✓	✓
SF503	Sample Management Facility {503}		✓	✓	✓	✓	✓
SF504	Repository Performance Confirmation Faci		✓	✓	✓	✓	✓
SF1008	Rail Operations Facility {1008}		✓	✓	✓	✓	✓
SF401	Ai r Intake Shaft Hoist Building {401}	✓	✓	✓	✓	✓	✓
SF402	Ai r Intake Shaft Winch Building {402}	✓	✓	✓	✓	✓	✓
SF105	Auxiliary Air Intake {105}	✓	✓	✓	✓	✓	✓
SF301	Salt Handling Shaft Hoist Building {301	✓	✓	✓	✓	✓	✓
SF303	Salt Handling Shaft Operations {303}	✓	✓	✓	✓	✓	✓
SF203	Exhaust Shafts Monitoring Stations {203}	✓	✓	✓	✓	✓	✓
SF403	Air Intake Shaft Head Frame {403}	✓	✓	✓	✓	✓	✓
SF302	Salt Shaft Head Frame {302}	✓	✓	✓	✓	✓	✓
SF811	Telephone & Communications Interface {811}		✓	✓	✓	✓	✓
SF	Running Track				✓	✓	✓
SF1009	Oil & Grease Storage Bldg. {1009}				✓	✓	✓
SF1010	Compressed Gas bottle Storage Bldg. {1010}				✓	✓	✓
SF1002	Tailings Vehicle Shelter {1002}	✓	✓	✓	✓	✓	✓
SF581	Meterological Stations {581}				✓	✓	✓
SF505	Waste Receipt Support Facility {505}		✓	✓	✓	✓	✓
SF908	Visitor Center {908}				✓	✓	✓
SF1015	Recyclables Yard {1015}				✓	✓	✓
SF820	Topsoil Stockpile {Area 820}				✓	✓	✓
SF63	Site Clearing and Grading		✓	✓	✓	✓	✓
SF64	Security Fence		✓	✓	✓	✓	✓
SF65	Landscaping (including sidewalks		✓	✓	✓	✓	✓
SF66	Construction Temporary Facilities		✓	✓	✓	✓	✓
SF67	Substations (QTY)		✓	✓	✓	✓	✓
SF68	Hazardous Waste Staging Facility (601)		✓	✓	✓	✓	✓
SF69	Hazardous Material Storage Facility (101		✓	✓	✓	✓	✓
SF70	Salt Water Evaporation Pond						
SF71	Misc Equipment		✓	✓	✓	✓	✓
SF72	Concrete Staging Area		✓	✓	✓	✓	✓
SF73	Gravel Staging Area		✓	✓	✓	✓	✓
SF??	Cask Inbound Trans. Pkg Lag Storage Area	✓	✓	✓	✓	✓	✓
SUB01	Salt Handling Shaft {300}	✓	✓	✓	✓	✓	✓
SUB02	Air Supply Shaft {400}	✓	✓	✓	✓	✓	✓
SUB03	Air Exhaust Shaft {200}	✓	✓	✓	✓	✓	✓
SUB04	Waste Shaft {100}		✓	✓	✓	✓	✓

6. Schedule and Cost Estimates

The costs and schedules for all Cases were developed by the collective experiences of the task team. The scope of work provided by DOE for this study specified a 40-year operational life. The team used the same durations for the Conceptual, Preliminary and Final Designs and Construction and Start-up periods previously developed in the prior salt repository study. The costs and schedules presented in this section do not include the important activities of site screening, site characterization, site selection and these may vary significantly across the cases. The costs and schedules of site screening, site characterization, and site selection cannot be estimated with confidence at this time because there is not enough directly relevant data.

6.1 Schedule Range

The schedule for the repository was developed for four major phases: 1) design and construction (which includes conceptual, preliminary, and final design, construction and start-up activities), 2) operations, 3) closure and 4) post closure monitoring. The schedule was developed as a point estimate for a generic location repository and the team applied uncertainty based on their professional judgment which results in the schedule ranges presented in Table 7-1. Some schedule savings are possible for the WIPP extension cases but this was not investigated during the study due to the time limitations imposed.

Table 6-1 Repository Schedule Estimates

Phase	Duration Range (yrs)
Conceptual Design	3 – 9
Preliminary Design	1.5 – 2
Final Design	4 – 5.5
Construction and Start-up	6.5 – 8
Total Design and Construction	15 - 24.5
Operations	40 or 100
Closure	9 – 12
Post Closure Monitoring	50

6.2 Design, Construction, Start-up, Operations, Closure and Monitoring Cost Range

The design, construction start-up, operations, closure and monitoring cost (DCSOCMC) estimate range is determined based upon the schedule (Section 6.1) and type of activities conducted in each of the four schedule phases.

Table 6-2 provides a summary of the DCSOCMC range for each of the five cases. The costs are detailed by the same estimating categories in the original Salt Repository Study. These results indicate the cost of disposing of HLW ranges from $13.1 B to $17.9 B in 2012 dollars. This range is established by taking the low from Case 3 (HLW disposed in a generic location) and the high from Case 2 (HLW disposed in a WIPP extension). Although Case 2 is slightly higher than Case 3, the low-high range essentially overlaps indicating there is little cost difference between the two cases. This conclusion is driven by the need for new surface facilities to accommodate the larger than WIPP design basis canisters and emplacement capacity.

The incremental cost of adding the DOE SNF (3,542) canisters to a generic location repository is approximately $120 to 160 million or $34 K to $45 K per canister.

The incremental cost of adding the Naval Fuel to a generic location repository is approximately $1.9 to $2.8 million each. This large difference between the DOE SNF and the Navy SNF is due to the additional repository emplacement area and the additional surface infrastructure requirements. The study team recommends alternative approaches be considered for the Naval Fuel.

A “pilot” Defense Waste Repository which disposes of the SRS only canisters (Case 1) ranges from $8.6 to $11.6B or $1.1 to $1.5M for each canister. The economy of scale can be observed by comparing Cases 1 and Case2 (or3) in which the cost per canister decreases by about half.

Table 6-2 also provides the DCSOCMC in escalated dollars. A centroid of expenditure methodology was utilized to develop escalated cost estimate ranges. This method uses a single cumulative escalation rate as published by the DOE Office of Engineering and Construction Management web page. The rate is calculated to the centroid of expenditures. This method was used to calculate both the TPC and DCSOCMC escalated cost ranges.

Table 6-3 provides the DCSOCMC cost detailed by the schedule phase in both 2012 and escalated dollars.

6.3 Facilities Design and Construction Cost

Table 6-3 provides a summary of the facilities design and construction cost for the surface and sub-surface facilities for the five cases considered in this study. The surface facilities are described in Section 5.

Table 6-2 Design, Construction, Start-up, Operations, Closure and Monitoring Cost Summary by Cost Element

	Case 1		Case 2		Case 3		Case 4		Case 5	
	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range
FACILITY DESIGN, CONSTRUCTION & STARTUP	1,750	2,522	3,938	5,473	3,749	5,140	3,754	5,146	4,110	5,672
OPERATIONS & MAINTENANCE (O&M)	3,665	4,747	3,798	4,919	3,722	4,820	3,731	4,831	3,731	4,831
CLOSURE	717	1,143	717	1,143	717	1,143	717	1,143	717	1,143
WASTE PACKAGES	1	1	3	3	3	3	3	4	3	4
REGULATORY & LICENSING	268	277	343	354	806	840	806	840	806	840
MONITORING	756	1,031	1,375	1,875	1,188	1,620	1,291	1,761	1,455	1,985
PERFORMANCE CONFIRMATION PROGRAM	272	371	623	849	601	820	602	821	654	892
INTEGRATION	1,116	1,518	2,431	3,307	2,286	3,110	2,286	3,110	2,511	3,416
DCSOCMC	**$ 8,550**	**$ 11,610**	**$ 13,230**	**$ 17,930**	**$ 13,080**	**$ 17,500**	**$ 13,200**	**$ 17,660**	**$ 13,990**	**$ 18,790**
DCSOCMC (including Escalation)	**$ 23,860**	**$ 40,840**	**$ 36,940**	**$ 63,050**	**$ 36,500**	**$ 61,540**	**$ 36,830**	**$ 62,110**	**$ 39,060**	**$ 66,070**

Table 6-3 Design, Construction, Start-up, Operations, Closure and Monitoring Cost Summary by Schedule Phase

	Case 1		Case 2		Case 3		Case 4		Case 5	
	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range
Site Screening	75	101	133	180	197	264	197	264	204	274
Conceptual Design & Site Characterization Phase	533	701	1,103	1,465	1,205	1,546	1,210	1,552	1,301	1,677
Preliminary Design Phase	151	206	324	440	328	435	328	436	355	473
Final Design Phase	340	471	728	994	725	968	726	970	791	1,063
Construction Phase	1,735	2,447	3,359	4,638	3,273	4,451	3,284	4,465	3,565	4,880
Operational Phase	4,630	6,051	6,163	8,120	5,974	7,820	6,027	7,891	6,289	8,248
Closure	901	1,386	1,082	1,630	1,078	1,614	1,089	1,629	1,119	1,669
Post Closure	180	246	336	458	292	398	328	447	364	497
DCSOCMC	**$ 8,550**	**$ 11,610**	**$ 13,230**	**$ 17,930**	**$ 13,080**	**$ 17,500**	**$ 13,200**	**$ 17,660**	**$ 13,990**	**$ 18,790**
DCSOCMC (including Escalation)	**$ 23,860**	**$ 40,840**	**$ 36,940**	**$ 63,050**	**$ 36,500**	**$ 61,540**	**$ 36,830**	**$ 62,110**	**$ 39,060**	**$ 66,070**

Table 6-4 Facilities Design and Construction Cost Cases 1 to 5

Facilities	Case 1		Case 2		Case 3		Case 4		Case 5	
	Low Range $ millions	**High Range $ millions**	**Low Range $ millions**	**High Range $ millions**	**Low Range $ millions**	**High Range $ millions**	**Low Range $ millions**	**High Range $ millions**	**Low Range $ millions**	**High Range $ millions**
Major surface facilities	40	50	626	791	755	953	757	954	757	954
Balance of Plant and support surface facilities	137	170	421	521	451	559	454	562	454	562
Sub-surface facilities	918	1,412	1,399	2,152	1,104	1,699	1,104	1,699	1,334	2,053
Total Facilities Construction Cost	**$ 1,095**	**$ 1,632**	**$ 2,445**	**$ 3,464**	**$ 2,311**	**$ 3,210**	**$ 2,314**	**$ 3,215**	**$ 2,544**	**$ 3,569**
Total Facilities (including Escalation)	**$ 1,830**	**$ 3,435**	**$ 4,085**	**$ 7,293**	**$ 3,861**	**$ 6,758**	**$ 3,867**	**$ 6,767**	**$ 4,251**	**$ 7,513**

7. Conclusions and Recommendations

Based on the analysis provided in this scoping study, disposal of defense waste in a salt repository is feasible within a reasonable schedule and cost. The time to design, construct and start-up a salt repository is estimated to be 15 – 25 years after site selection. Some schedule savings are possible for the WIPP extension cases but this was not investigated during the study due to the time limitations imposed.

The most significant assumption in the approach used to develop the disposal concept is that the waste canisters can be directly emplaced on the disposal room floor and covered with run-of-min salt immediately. Additional engineered barriers will not be required.

The large Naval Fuel canisters are essentially incompatible with a shaft-hoist repository horizon access system. The hoist required exceeds industry standards and is not likely commercially available. The study team recommends alternatives be considered for this material including repackaging into packages compatible with the shaft-hoist access systems.

8. References

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