Title 40 CFR Part 191
Subparts B and C
Compliance Recertification Application 2014
for the
Waste Isolation Pilot Plant

Appendix WRAC-2014
Waste Removal After Closure

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Field Office
Carlsbad, New Mexico

Compliance Recertification Application 2014
Appendix WRAC-2014

NOTE

This Appendix is a revised version of the Compliance Certification Application (CCA) Appendix WRAC (DOE 1996). The revision to Appendix WRAC was made in response to Environmental Protection Agency (EPA) completeness comments on the 2014 Compliance Recertification Application (EPA 2015).

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Acronyms and Abbreviations

CAG	Compliance Application Guidance
CFR	Code of Federal Regulations
CH	contact-handled
DOE	Department of Energy
DRZ	disturbed rock zone
EPA	U.S. Environmental Protection Agency
HEPA	high efficiency particulate air
HSLA	high-strength low alloy
LWA	Land Withdrawal Act
MB	marker bed
MgO	magnesium oxide
RH	remote-handled
SWB	standard waste box
TRU	transuranic
WHS	waste handling shaft
WIPP	Waste Isolation Pilot Plant

WRAC-1.0 Introduction

This Appendix is a revised version of the Compliance Certification Application (CCA) Appendix WRAC (DOE 1996). This revision was made in response to Environmental Protection Agency (EPA) completeness comments on the 2014 Compliance Recertification Application (EPA 2015). The analysis discussed in this appendix documents the techniques that could be applied in removing transuranic (TRU) waste from the Waste Isolation Pilot Plant (WIPP) repository after disposal. Title 40 Code of Federal Regulations (CFR) § 191.02(l) defines disposal of waste in a mined geologic repository as occurring ". . .when all of the shafts to the repository are backfilled and sealed." This report will serve to document compliance with the requirement in 40 CFR § 191.14(f) that the disposal system not preclude ". . .removal of most of the waste . . .for a reasonable period of time after disposal." The removal discussion is based on currently available technologies. The reasoning for waste removal is not considered relevant except that it is assumed the packaging, transportation mechanism and destination for the removed waste will be known. Transportation methods, end use, and destinations of the removed waste are not considered in this analysis.

WRAC-2.0 WIPP Mission Description

The WIPP is a research and development facility of the U.S. Department of Energy (DOE) designed to demonstrate the safe transportation, handling, and disposal of defense-generated TRU radioactive waste. The facility is located 26 miles (42 kilometers) east of Carlsbad, New Mexico. The repository is located in a salt deposit, 2,150 feet (655 meters) below ground. The waste is shipped to the facility from numerous generator sites around the United States and placed in the underground repository for disposal. Figure WRAC-1 details the WIPP location and Figure WRAC-2 contains a diagram of the WIPP surface and underground facilities. The facility began disposal operations in 1999. A comprehensive description of the WIPP disposal system and its operations is presented in Chapters 2.0 and 3.0 of the Compliance Certification Application (CCA: DOE 1996). A description of the operations and planned closure of the facility is in Chapter 3.0 of the CCA. The waste was originally described in Chapter 4.0 of the CCA, but the current waste information and important waste-related parameters used in performance assessment (PA) can be found in Section 24 of the CRA-2014 (DOE 2014a).

WRAC-3.0 Analytical Scope

This analysis examines the feasibility of removing emplaced waste from the WIPP repository after closure. The regulatory and technical bases for removal are discussed. The emplacement and closure scenarios are defined to describe the condition of the repository and waste after closure. The sequence of steps for removal is described in this Appendix and includes a detailed discussion of their implementation. Assuming that the technology and equipment used today to mine materials deposited millions or billions of years ago will be available in the future, it is technically feasible to remove the waste any time during the regulatory time frame. The feasibility of waste removal is demonstrated by describing a method for waste removal.

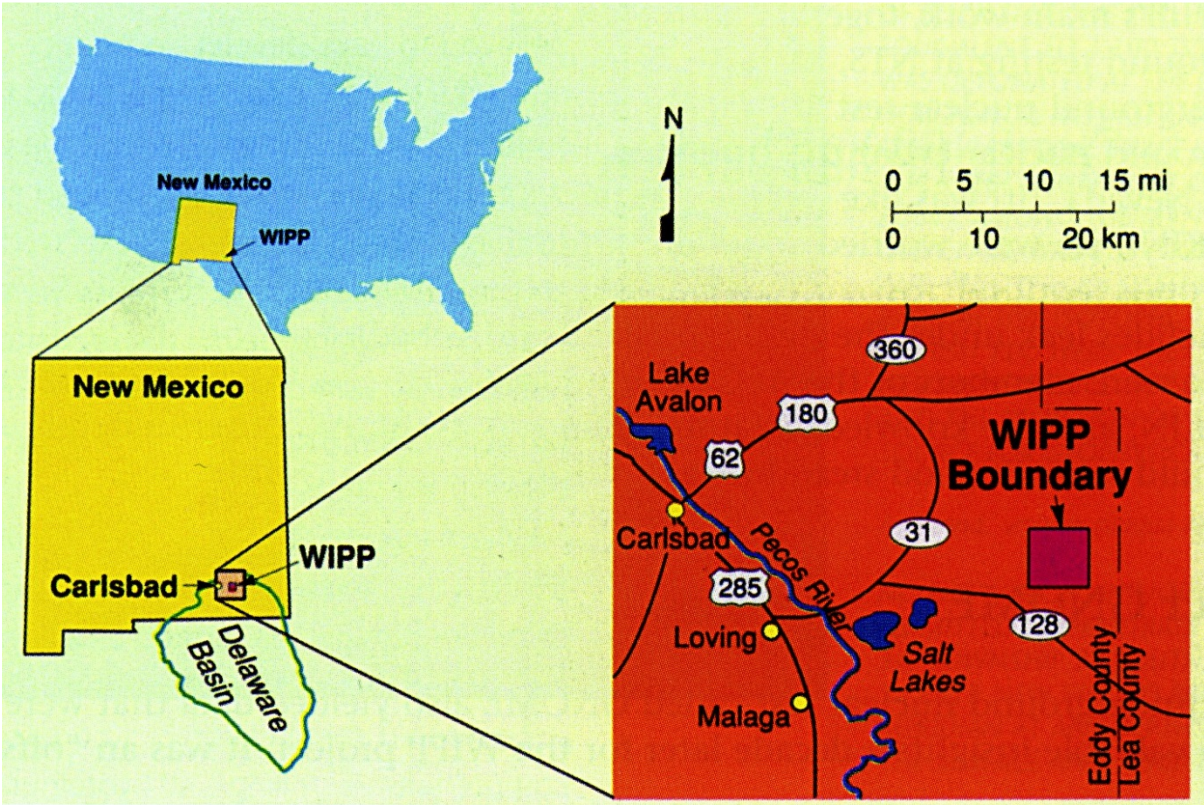

Figure WRAC-1. General Location of the WIPP Facility

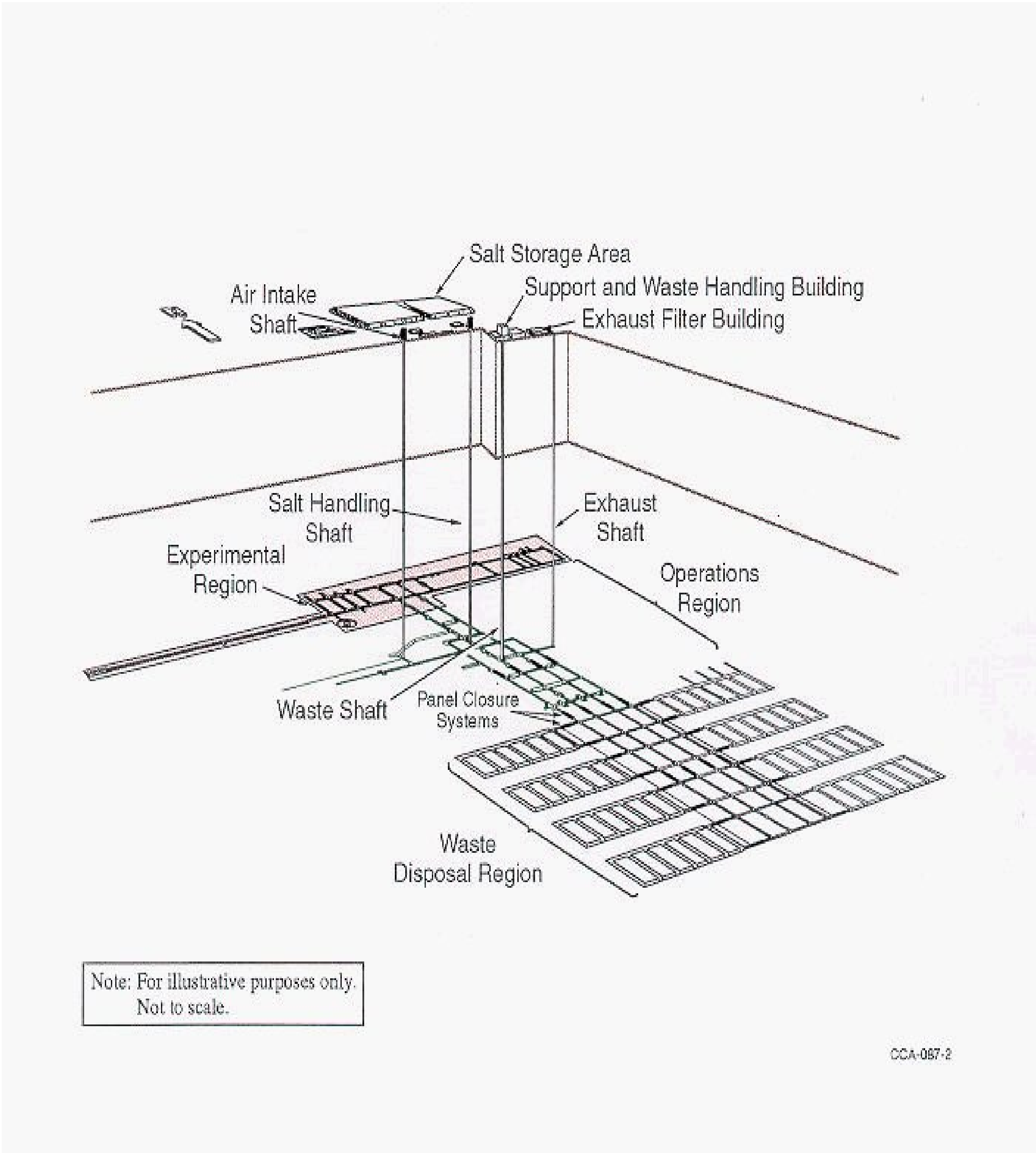

Figure WRAC-2. WIPP Surface and Underground Facilities

For the purposes of this feasibility analysis, it is important to distinguish the difference between waste removal and waste retrieval. Waste removal differs from waste retrieval in that removal refers to actions taken after the repository is closed and sealed. Retrieval, which is essentially the reverse of emplacement, refers to recovering the waste prior to repository closure. This analysis specifically deals with waste removal.

WRAC-4.0 Regulations Applicable to This Feasibility Analysis

As an assurance requirement in 40 CFR Part 191, waste removal is one of several cautious steps that are to be taken to reduce uncertainties inherent in the long-term predictions of disposal system performance. The EPA believes that recovery of the waste, though not necessarily easy or inexpensive, should not be precluded in the event some future discovery or insight made it clear that the wastes needed to be removed. The EPA provides specific insights regarding the implementation of this requirement as well as criteria in 40 CFR Part 194 for judging the adequacy of the DOE's demonstration of compliance to this requirement. Each is discussed below.

WRAC-4.1 40 CFR Part 191 Requirements

40 CFR § 191.14(f) states, "Disposal systems shall be selected so that removal of most of the waste is not precluded for a reasonable period of time after disposal". With respect to the recovery of waste after disposal, the preamble to 40 CFR Part 191 (50 *Federal Register* (FR) 38082) states that

...any current concept for mined geologic repository meets this requirement without any additional procedures or design features. For example, there is no intent to require that the repository shafts be kept open to allow future recovery. To meet this assurance requirement, it only need be technically feasible (assuming current technology levels) to be able to mine the sealed repository and recover the waste - albeit at substantial cost and occupational risk" (EPA 1985).

WRAC-4.2 40 CFR Part 194 Certification Criteria

40 CFR § 194.36 states that

Any compliance application shall include documentation which demonstrates that removal of waste is feasible for a reasonable period of time after disposal. Such documentation shall include an analysis of the technological feasibility of mining the sealed disposal system, given technology levels at the time a compliance application is prepared.

By way of guidance for the requisite analysis referenced in the criterion, the EPA has provided a specific list of expectations in its Compliance Application Guidance (CAG) (EPA 1996). In the CAG, the EPA states:

EPA expects the required analysis to include:

- *a sequence of procedures or steps which would need to be accomplished in order for waste to be removed from the disposal system after closure;*

- *a discussion of how the sequence described above could be implemented, including descriptions of how currently available equipment and technologies could be utilized; and*

- *an estimate of how long after disposal it would be technologically feasible to remove the waste, based on the disposal system design and closure, and using the system and equipment described in the application. (EPA 1996, 66)*

The following feasibility analysis examines and addresses this criterion and the implementation guidance. Background information is provided as part of the feasibility analysis. This background information includes a description of the disposal system and the waste at the time of disposal and the assumed condition at the time of removal (to the practicable extent to which this condition can be anticipated).

WRAC-5.0 WIPP Repository Description

The WIPP disposes TRU waste in rooms 2,150 feet (655 meters) below the surface. These rooms are mined in a bedded halite (salt) layer known as the Salado Formation (hereafter referred to as the Salado). The Salado is approximately 2,000 feet (610 meters) thick at the repository location. Figure WRAC-3 shows the general geologic cross section of the WIPP site. The underground repository is mined on three general levels, the north area and two waste areas. The northern most area includes mined areas that were used for early experiments and is mined at a level above the shaft landings and disposal areas. The north area is used today for operations and includes areas for ongoing experiments. Waste is emplaced in the disposal areas, which are comprised of eight panels, each panel composed of seven rooms, and the inter-connecting access entries (drifts) which are identified as Panels 9 and 10. The rooms are mined to the initial dimensions of 300 feet long by 33 feet wide by 13 feet high (91 meters by 10 meters by 4 meters). Half of the disposal area is mined at a higher horizon. Panels 3, 4, 5 and 6 are mined approximately six feet higher than the other panels. The access drifts include ramps connecting the two levels. The repository layout is shown in Figure WRAC-4. A complete technical description of the repository including its geotechnical performance is found in annual Geotechnical Analysis Reports or GARs (DOE 2014b).

The waste is composed of radioactive and hazardous waste materials generated by the DOE's nuclear weapons programs. The materials are primarily laboratory and production equipment such as glassware, solidified spent solvents, cleaning rags, laboratory clothing, solidified sludges, metal tools, pipes, plastics, and paper. TRU waste is defined as waste contaminated with alpha emitting radionuclides having atomic numbers greater than 92, half-lives greater than 20 years, and a specific activity greater than 100 nanocuries per gram. Some of the waste to be disposed of at WIPP will contain hazardous constituents as defined by the Resource Conservation and Recovery Act (RCRA). This waste is referred to as TRU mixed waste. The waste is currently generated or stored at numerous sites in the United States. Current waste emplacement volumes are reported on an ongoing basis in the WIPP Waste Data System.

There are two classifications for the TRU waste, contact-handled (CH) TRU and remote-handled (RH) TRU. The CH-TRU waste is defined as TRU waste packaged in containers whose maximum surface dose rate does not exceed 200 millirem per hour. Surface dose rates greater than 200 millirem per hour are classified as RH-TRU waste. For emplacement into the WIPP the RH-TRU surface dose rates cannot exceed 1,000 rems per hour with a maximum total of five percent of the canisters exceeding 100 rems per hour. The total maximum activity for RH-TRU waste at WIPP cannot exceed 5.1 million curies. These limits including a maximum TRU waste volume of 6,200,000 cubic feet (175,588 cubic meters) are established by the Land Withdrawal Act (LWA). The actual emplaced volumes, waste stream information and waste emplacement locations are kept as long-term records and will be available for an appreciable period of time after closure which will aid in waste removal activities. This information includes the specific locations of all CH and RH containers and includes the location of a few shielded containers that are planned to be emplaced within the areas used to emplace CH waste.

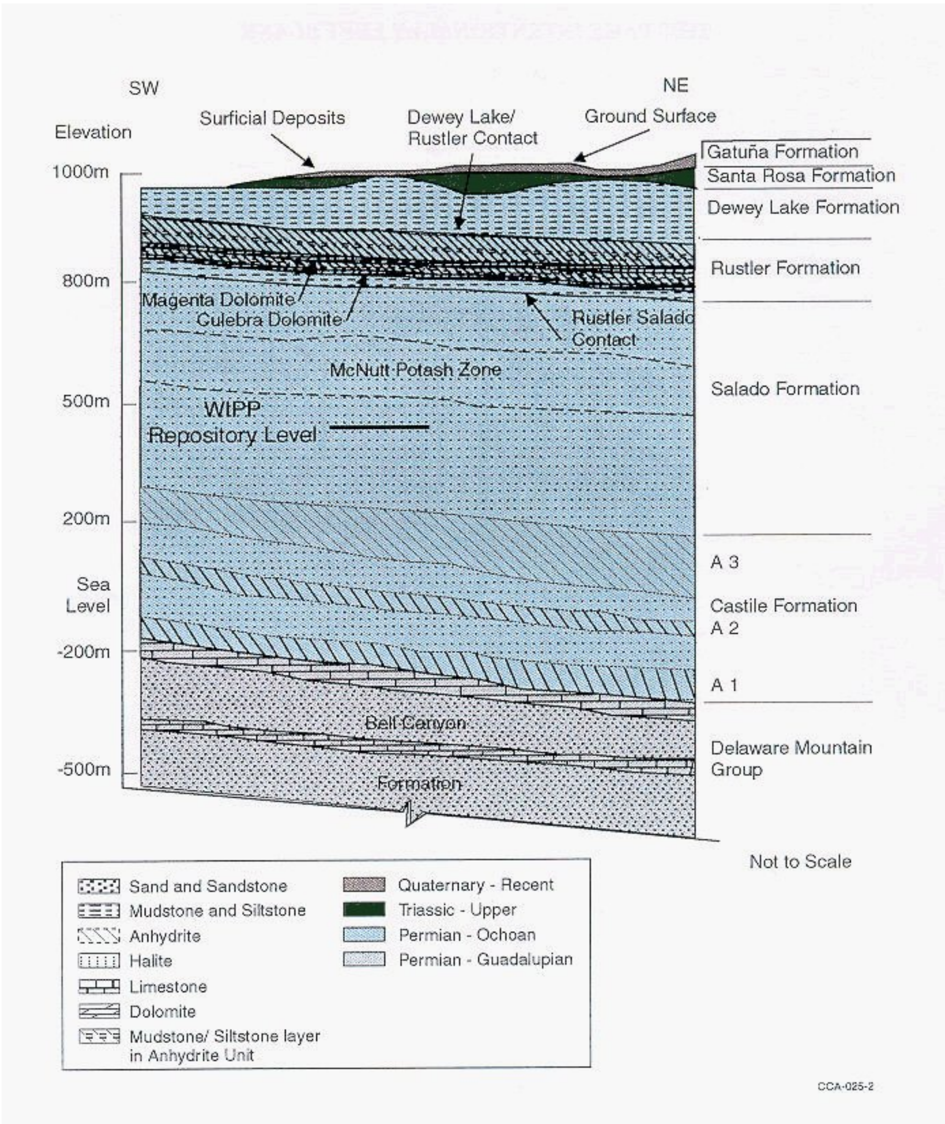

Figure WRAC-3. Generalized Geologic Cross Section

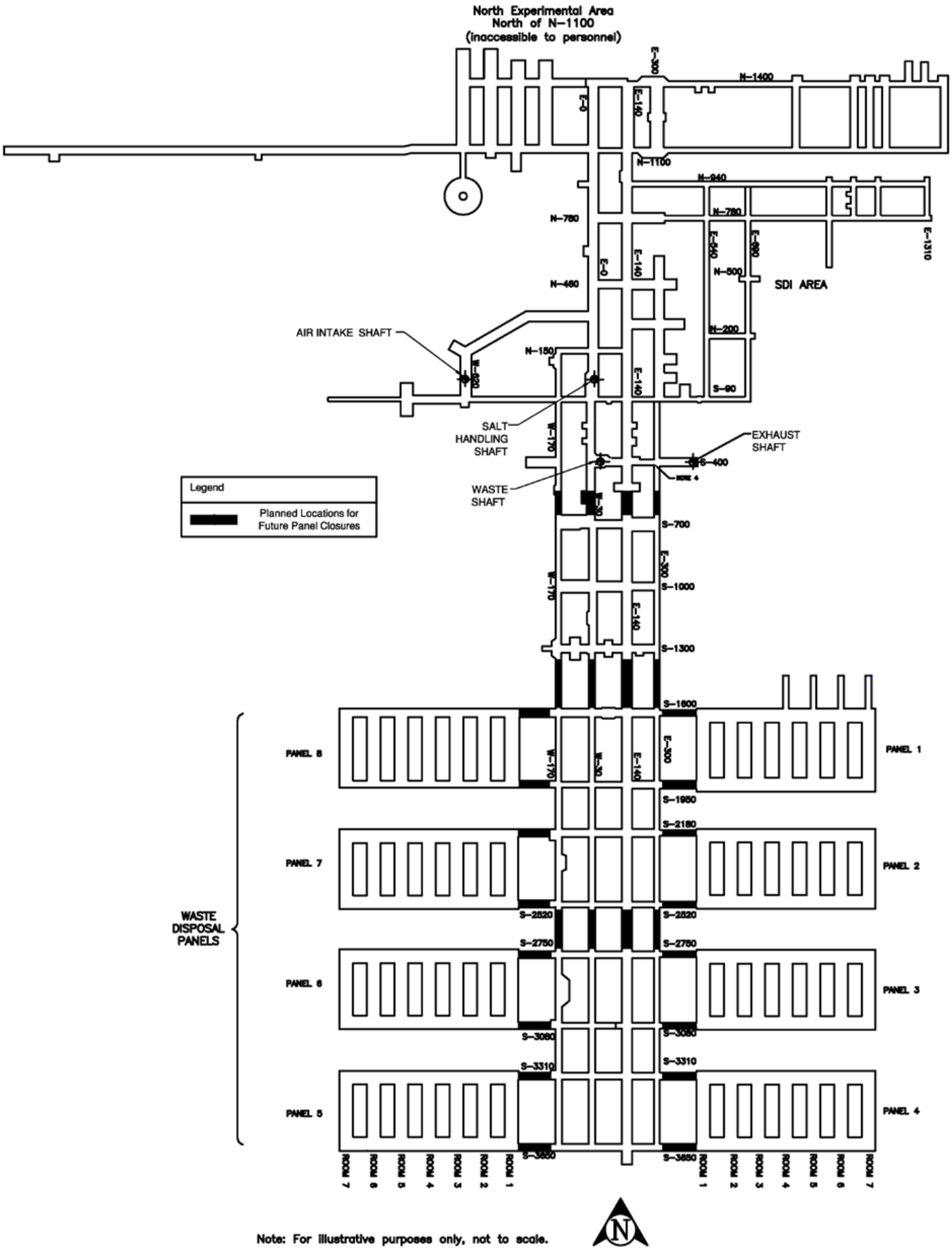

Figure WRAC-4. Repository Layout

The high radiation associated with RH-TRU waste is due to the presence of isotopes of cesium, strontium, barium, plutonium, and yttrium. The longest half-life among these isotopes is 30.0 years. Therefore, after about 300 years, the isotopes will have gone through a minimum of 10 half-lives and their radioactivity, relative to the longer lived isotopes associated with the CH-TRU waste, will be significantly diminished. For this reason, in discussion of the removal of waste after 300 years, the DOE does not distinguish between the RH-TRU and CH-TRU types.

The majority of CH-TRU waste has been shipped to the WIPP in either 55-gallon (208-liter) drums or standard waste boxes (SWBs). The 55-gallon drums are wrapped together in an arrangement of seven drums called seven-packs. A list of the waste containers used in the repository is shown in Table WRAC-1. A list of the emplaced waste volumes is shown in Table WRAC-2. The waste container is the outermost container and may include other overpacked containers, such as 55-gallon drums or pipe overpacks. The waste containers are shown in Figure WRAC-5. Rows of containers are placed in the rooms, generally three high, with a bag of magnesium oxide placed on top of most of the stacks to achieve the quantity needed to meet the regulatory requirements of an engineered barrier. The waste will also be emplaced in the panel access entries.

Table WRAC-1. Container Types and Emplaced Waste Volumes (As of 2/28/2015; DOE 2015)[1]

Emplaced Waste Containers	Number of Containers in Repository
55-Gallon Drum	116,955
Standard Waste Box	12,846
Ten-Drum Overpack	6,047
85-Gallon Drum (short and tall)	5
100-Gallon Drum	34,255
Standard Large Box 2S	228
Removable Lid 72-B RH Canisters	701
Fixed Lid 73-B RH Canister	18
Shielded Containers	9

Table WRAC-2. Emplaced Waste Volumes (As of 2/28/2015; DOE 2015)[2]

Emplaced Waste	Volume (m^3)
CH Container Volume	90,627
RH Container Volume	357
Total Waste Volume	90,984

After a panel is filled, a closure system is constructed to isolate the waste from further operations. The original closure system design used a block wall and called for a large concrete monolith. Block walls have only been constructed in Panels 1, 2 and 5. Steel bulkheads have been emplaced in the entryways to Panels 3, 4 and 6. The concrete closure design has been

[1] The date for this information is more current than that of the CRA-2014 and may differ from the information in the CRA-2014.
[2] The date for this information is more current than that of the CRA-2014 and may differ from the information in the CRA-2014.

replaced with a 100 foot run-of-mine-salt-based panel closure design that will be emplaced in all of the panel entries prior to repository closure. The closure design is shown in Figure WRAC-6 and described in CRA-2014 Appendix PA, Section PA-4.2.8 (DOE 2014a).

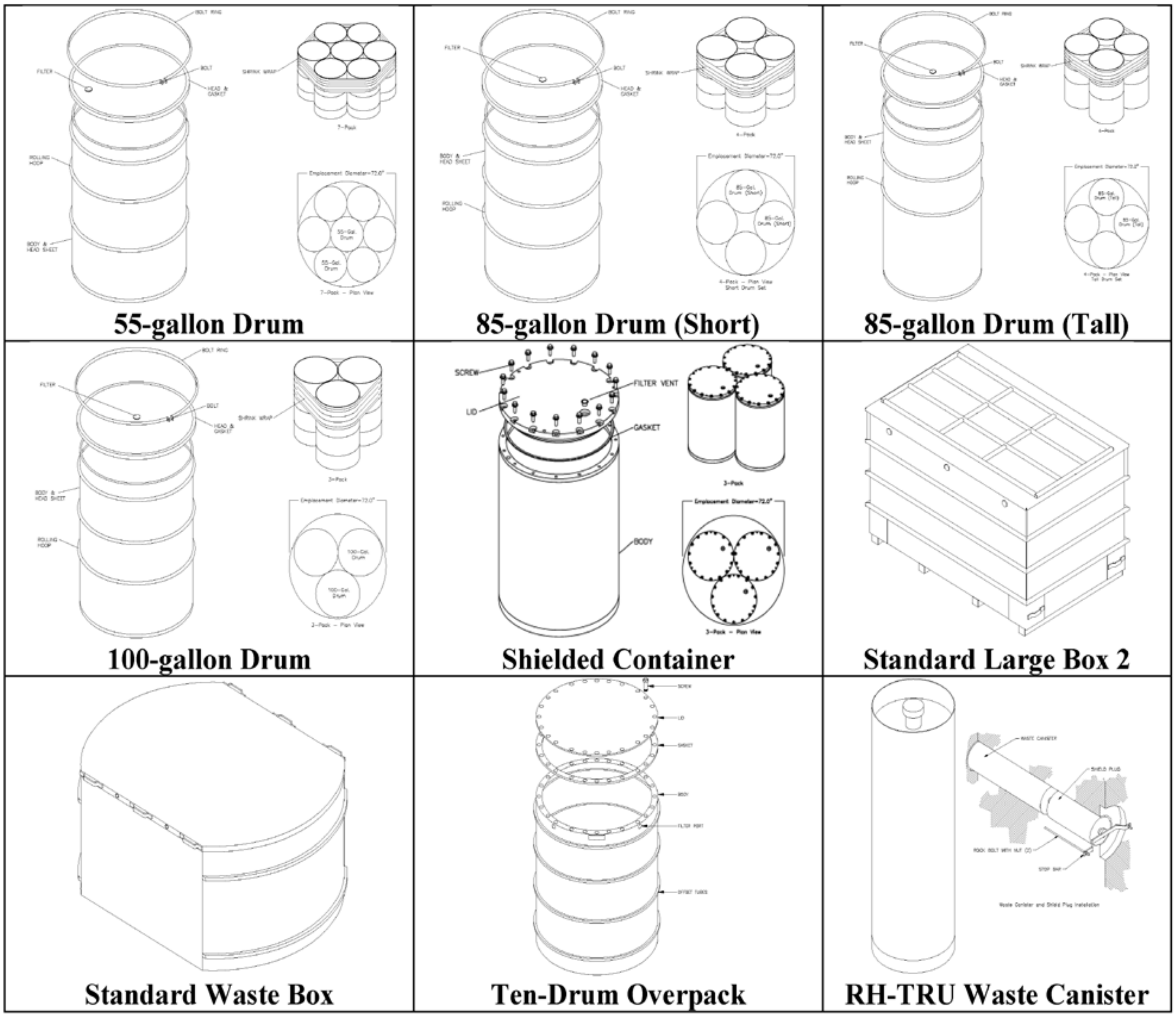

Figure WRAC-5. SWB and Seven-Pack Configurations

An engineered barrier consisting of magnesium oxide (MgO) is placed over the containers of CH-TRU waste. The MgO is emplaced in 3,000-lb or 4,200-lb super sacks on top of the waste stack (see CRA-2014 Appendix MgO for more detailed information on MgO emplacement). The MgO super sacks are intended to burst as the room creeps closed, allowing the granular materials to be exposed to the room environment. Alkaline earth oxides (such as MgO) are known to readily react with water to form hydroxides. These hydroxides are free to react with carbonic acid that may form in the disposal room. The reaction buffers the brine to a pH which serves to reduce the amount of actinides in solution.

The RH-TRU waste canisters are constructed of painted carbon steel, 26 inches (66 centimeters) in diameter with a maximum length of 121 inches (307.3 centimeters). The maximum weight of a filled canister is 8,000 pounds (3628.7 kilograms) (DOE 1991). In order for personnel to handle the RH-TRU waste, the RH waste canisters must be shielded to reduce radiation levels to allowable limits. The shielded facility cask is used to transport RH-TRU waste to the underground. The RH-TRU waste canisters are emplaced in the disposal room walls prior to CH-TRU waste emplacement in that room. The waste canister is pushed out of the facility cask and into a horizontal borehole in a disposal room wall. The borehole is then closed with a shield plug. The shield plug is a cylinder 29 inches (73.7 centimeters) in diameter and 70 inches (177.8 centimeters) long with a wall thickness of 1.5 inches (3.8 centimeters). The bottom of the plug is constructed from a 5-inch (12.7-centimeter) thick plate. The 3-inch (7.6-centimeter) thick top plate also has a standard waste handling pintle. The total weight of the plug is approximately 4,200 pounds (1,905 kilograms). Currently, RH waste has not been emplaced in every room of the repository that has CH waste. Some RH waste has been emplaced in shielded containers along with the CH waste, and not in the disposal room walls. As is done for the CH waste, all emplaced RH-TRU waste locations are recorded and retained as a permanent record.

WRAC-5.1 Repository Configuration at the Time of Closure

The anticipated final configuration of the repository at the time of closure is shown in Figure WRAC-6. This is the configuration that is used as input to the conceptual model developed to predict repository performance. The model geometry used in PA is shown in CRA-2014 Appendix PA, Figure PA-12 (DOE 2014a). The important regions include the waste disposal panel, panel closures, the panels and access drifts in the North and South rest-of-the repository area, the shaft region, the operations region, and the experimental region at the north end of the excavation. In addition, the repository geometry conceptual model described in Appendix PA incorporates the stratigraphic units surrounding the repository into the model as discrete regions. These include the Salado Formation outside the disposal region, MB138, Anhydrite Layers A and B, the disturbed rock zone and MB139. Parameter values have been assigned to important properties (such as porosity and permeability) of these various regions. Initial values and value ranges used in the CRA-2014 PA are summarized in Kicker and Herrick 2013.

The LWA limits the total disposed TRU waste to 6,200,000 cubic feet (175,600 cubic meters). After waste emplacement is complete, the surface structures will be decontaminated and decommissioned. This will include decontaminating the surface facilities and dismantling the aboveground structures. TRU waste generated by these activities will be emplaced in the repository and the last waste panel will be closed. The four shafts will be sealed using crushed Salado salt in combination with other materials such as concrete, cementitious grout, clay, and asphalt. CCA Appendix SEAL details the shaft seal design (DOE 1996).

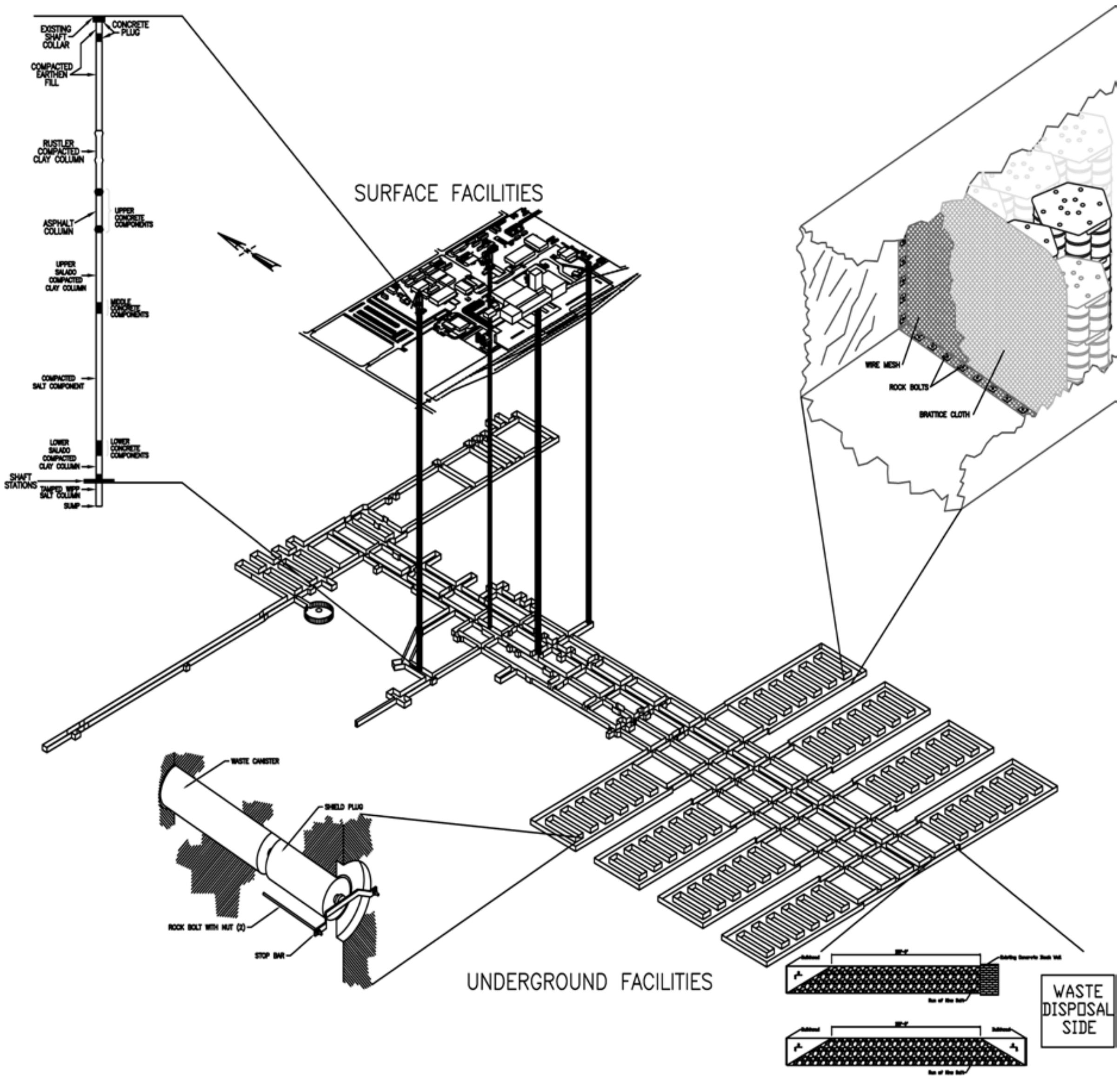

Figure WRAC-6. WIPP Repository at Time of Closure

WRAC-5.2 Repository Condition at Time of Removal

The requirement to remove the waste does not specify when or if removal would occur; only that removal not be precluded. The condition of the repository is time dependent with respect to salt reconsolidation, waste compaction and decay. For the purposes of this analysis, the DOE assumes that the reason for removal is the result of a discovery or insight gained by a future generation and not the result of an event that necessitates removal. As the result of this assumption, there are no time or cost limits imposed on the removal process in this analysis. Radioactive waste within the disposal region can be removed at whatever rate is necessary to safely manage occupational and public exposure.

Additional assumptions include the following.

- The reason for waste removal is known and what will be done with the waste is unimportant for this analysis. This analysis need only demonstrate removal feasibility.
- The length of time the repository has been closed at the time of removal is known to those planning the removal and the anticipated conditions of the waste panels and panel closure can be determined for use in designing removal systems (see CRA-2014 Appendix PA, Section PA-4.2.3 [DOE 2014a] for a discussion of rock creep and porosity and permeability values assumed for performance assessment).
- The waste containers have been breached.
- Removal of most of the waste means that all waste within the disposal region will be removed, however any contamination that may have migrated into the marker beds and may have moved out of the disposal region will not be removed.

Numerical calculations performed for the repository are focused on predictions of performance over a 10,000-year period. In the shorter term, the configuration of the excavation and waste within the repository is changing as it reaches a steady state configuration. As steady state is reached, the brine inflow rate is affected by the potential increasing pressure in the repository caused by gas generation and creep closure. These three phenomena are related in the numerical modeling that is detailed in CRA-2014 Appendix PA. All of these phenomena and the various associated states of the excavation need to be considered in evaluating the feasibility of removal. In no case, however, are conditions expected to render removal impossible. The repository was originally mined for disposal operations and the area can be mined again. The last PA run prior to repository closure will be included in archived records (see CCA Appendix PIC [DOE 1996]). This information can be used to help predict the conditions in the repository at the specific time of waste removal.

Gas generation affects pressure within the excavation, which in turn is an important mechanism in creep closure. The computer simulation of this process uses an average-stoichiometry model to estimate the potential for gas generation in the waste disposal region. Modeling shows that gas pressure in the disposal room can range from slightly above atmospheric to near lithostatic over the 10,000-year period. The model assumes that interbed fracturing occurs at high pressures thereby limiting pressure buildup. If the agency removing the waste in the future anticipates that high pressures are present, techniques are available to detect and safely relieve such pressures. Such techniques are currently in use in the WIPP to prevent dangerous pressure blowouts from localized pressurized zones ahead of mining. The technique involves drilling small diameter probe holes into the rock ahead of the mining machine.

The DOE conceptualizes the Salado as a porous medium composed of several rock types arranged in layers, through which fluid flow occurs according to Darcy's Law. This model was chosen because it can be simulated using standard numerical techniques and because it is the most conservative of the three mechanisms in that it predicts the maximum rate and cumulative volume of brine inflow. Two rock types, impure halite and anhydrite, are used to represent the intact Salado. Near the repository, the disturbed rock zone (DRZ) has increased permeability compared to intact rock and offers limited resistance to flow between anhydrite interbeds and the repository. Except for the DRZ and anhydrite interbeds, under certain circumstances, this simulation assumes spatially constant properties for Salado rock. The inference is that there is little variation in large-scale averages of rock or flow properties across the disposal system. Assumptions about Salado flow in general are presented in CRA-2014 Appendix PA, Section PA-4.2 and CRA-2014 Appendix MASS, Section MASS-5 and 6 (DOE 2014a).

In the computer simulation, brine flows from the Salado and into the repository in response to fluid potential gradients that form over time. Because of the low permeability of the impure halite and relatively small surface area of the excavation, direct brine flow between the impure halite and the repository is limited. The interbeds, however, can serve as conduits for brine flow between the impure halite and the repository. Conceptually, brine flows laterally along higher-permeability interbeds towards or away from the repository and vertically between the interbeds and the lower-permeability halite (DRZ).

Alternatively, in the modeling for the disturbed case, brine could flow into the repository as the result of a drilling intrusion that connects a disposal panel with postulated brine reservoir in the Castile Formation. In such a case, a portion or all of the excavation could be saturated with brine. Removal feasibility should consider a range of brine saturation from dry to fully saturated.

Creep closure of the excavation is the focus of a computer model that implements the repository processes associated with rock properties in the repository rooms and the shafts. The amount of waste consolidation resulting from creep closure, and the time it takes to consolidate the waste, are governed by properties of the waste (waste strength), properties of the surrounding rock, the dimensions and location of the room, and the quantities and pressure of fluids present in the room. Creep closure of waste disposal areas will cause their volume to decrease as the Salado deforms to consolidate and encapsulate the waste, changing waste porosity and permeability. Waste strength and fluid pressure may act to resist creep closure. The conceptual model implementing creep closure is discussed in CRA-2014, Appendix PA, Section PA-4-2-3 and CRA-2014 Appendix MASS, Section MASS-5 and 6 (DOE 2014a).

Fluids that could affect closure are (1) brine that may enter the repository from the Salado and is present in the repository when it is sealed, and (2) gas produced by reactions occurring during waste degradation. Closure and consolidation slowed by fluid pressure in the repository can be quantified according to the principle of effective stress:

$$\sigma_T = \sigma_e + p \qquad (1)$$

where σ_T is the stress caused by the weight of the overlying rock and brine (an essentially constant value), p is the pressure of the repository pore fluid, and σ_e is the stress that is applied to the waste matrix. As the waste matrix pore pressure increases, an increasing amount of overburden stress is supported by pore fluid pressure, and less overburden stress is supported by the strength of the waste matrix. Because of the strength, waste consolidation can cease even if pore fluid pressures do not reach lithostatic. If gas and brine quantities in the repository stabilize, creep closure will act to establish a constant pressure and void volume.

Creep closure becomes an important consideration for the removal process since it determines, to a major extent, the dimensions of the excavation that is needed to remove the waste and the condition of the rock that must be mined. Conditions where the creep has been minimal also indicate the situations where brine content or gas pressure are highest and represent the most hazardous pressure-related conditions.

WRAC-5.3 Summary of Conditions to be Anticipated for Removal Feasibility

Based on the descriptions in the preceding sections, there are five potentially hazardous conditions that should be anticipated in preparing for the removal of disposed waste. These are radioactivity, hazardous constituents, gas, brine, and rock integrity.

The amount of radioactivity depends on the time at which removal is initiated. Within the first 300 years of disposal, it may be necessary to consider treating (removing) RH-TRU and CH-TRU waste differently, because of higher radioactivity of the RH waste. Beyond 300 years, all the waste can be managed as CH-TRU waste because the inventory of Cs-137 and Sr-90 has decayed to very low levels. Regardless of when removal is initiated, the inventory of the waste documentation that will be accumulated by the DOE during operations and archived after closure will contain sufficient information to determine rather precisely the radioactivity levels to be anticipated and the locations of any containers of waste that may pose higher radioactivity hazards (i.e., shielded containers with RH waste).

Archived waste information would be available that could be analyzed to determine if there are potentially hazardous chemical waste properties, reactions or interactions that would need to be addressed during removal activities. With regard to the hazardous constituents in the waste, the volatile organics do not occur in sufficient quantities to pose a hazard as long as adequate ventilation is provided in areas that will be occupied by workers. Non-volatile hazardous constituents only pose threats if they are released during the removal process. Here, as with both the volatile components and the radioactive contaminants, proper ventilation control will be needed to provide adequate protection to workers, the public, and the environment. If environmental protection laws are the same at the time of removal as they are today, the planning for removal will require that the agency implementing removal provide detailed plans for controlling hazardous constituent contamination.

Gas pressures can range from one atmosphere (14.7 pounds per square inch or 0.101 megapascals) to pressures near 2,000 pounds per square inch (13 megapascals). Experience with mining in halite indicates that in virgin rock, high pressure zones are maintained because of the low permeability of the rock. Therefore, current mining activities are conducted in anticipation of pressure in areas where such pressures are known to exist. Due to the nature of the disposal operations and the panel closure practices, future pressures could vary from panel to panel.

Brine quantities can vary from little to no brine, caused by brine consuming processes such as corrosion, hydration of MgO and microbial degradation, to panels full of brine as the result of a borehole that connects the repository with a potential brine reservoir in the Castile Formation. As with gas, the quantity of brine can be different from one panel to the next because of the anticipated efficiency of the panel closures.

The amount of pore space in a disposal panel can be used to represent the degree of consolidation that has occurred due to creep closure. While brine and gas can act to maintain rather large pore volumes in a sealed panel, this condition is considered unlikely since creep closure acts fairly rapidly and it is unlikely that sufficient brine and subsequent gas will be available to support large pore volumes without an external source such as an intrusion involving a Castile brine reservoir. Because active controls are expected to deter human intrusion for at least 100 years after closure, an encounter with such a brine source is not expected during this time period. Although PA does not take credit for passive controls in the release calculations, the DOE believes passive controls will likely reduce human intrusions beyond 100 years. Consequently, without human intrusion, the repository is expected to reach its maximum closure before large quantities of brine are available.

Each of the factors above represents variable conditions that the removal planning activity must evaluate prior to actually removing the waste from the repository. None of these are expected to create conditions that will render the waste impossible to remove. However, the hazards imposed by the ranges of possible future conditions dictate careful hazard mitigation evaluations and appropriate planning prior to initiating waste removal.

WRAC-6.0 Sequence of Steps to Remove Waste

The DOE has identified a sequence of five phases for implementing removal:

Phase 1 — planning and permitting.

Phase 2 — initial aboveground setup and shaft sinking.

Phase 3 — underground excavation and facility setup of underground ventilation, radiation control, packaging areas, decontamination areas, maintenance, remote control center, and personnel support rooms.

Phase 4 — waste location and removal operations, including mining waste removal, packaging, package surveying and decontamination, transportation to surface, staging for off-site transportation, and off-site transportation.

Phase 5 — closure and D&D of the facility.

Each of the five phases is summarized below and described in detail in Section WRAC-7.0.

WRAC-6.1 Planning and Permitting

A decision to remove waste will initiate the planning and permitting phase. Permitting requirements will be based on governing regulations at the time removal is authorized. The planning and permitting program will identify all permits and research the available technologies at that time to determine available removal techniques and the condition of the repository. After initial research is completed, a plan will be drafted to itemize and schedule all removal activities. It is at this stage that initial estimates of the condition of the waste will be made. These will be based on the performance assessment results, the record of reassessments that may have been done as the facility was filled, the records of the waste that was actually placed in the facility, and any other information that may be useful in determining the status with regard to pressure, water content, contamination movement, and disposal room configuration. Strategies for evaluating the conditions in the repository and adjacent host rock will be developed. These may include surface drilling or drilling from within an initial excavation adjacent to the waste areas. Appropriate geophysical techniques and other remote sensing measures will be identified for determining the condition of the waste and adjacent areas in a manner that minimizes the hazards and chance for radiation exposure.

WRAC-6.2 Initial Aboveground Setup and Shaft Sinking

Aboveground support buildings will house the exhaust fans and any radiation control equipment such as HEPA filters, administration facilities, operations and engineering facilities, training facilities, safety facilities, maintenance support facilities, control center, waste staging and decontamination areas, container shipment loading and dock areas, warehouses (waste containers and maintenance), laboratories, and others as deemed necessary. Initial estimates of the amount of mining necessary will be made based on the results of the planning phase. The amount of mining will dictate the size and capacity of the surface support facilities and tailings piles.

WRAC-6.3 Underground Excavation and Facility Setup

After the shafts are completed, drifts will be run and ventilation paths will be established using conventional mine ventilation techniques. During shaft sinking, provision will be made to test the muck prior to its release to the surface to detect radioactive or hazardous constituent contamination. If such contamination is found, shaft muck will be isolated for future disposition. If contamination is minor, this material will likely be isolated from the environment by placing it back into the facility at the time of closure. Underground support and service areas will be excavated. The location of the shafts and initial excavations will be determined based on the anticipated brine and gas conditions. These areas will have sufficient intact salt between them and the waste areas that seepage or blowout of contaminated brine or gas into the shafts and service areas will be precluded. There are not expected to be any limitations on the amount of distance that can be specified between the wastes and the service areas. Support rooms will be excavated for maintenance, control, and packaging. Air locks will be constructed to provide the necessary level of ventilation control and separation between contaminated and non-contaminated areas. All equipment required for removal, packaging, and related support equipment will be installed.

Excavation will be in two stages. Initial excavation will not contact waste and will provide for mine support rooms, haulage drifts, ventilation, and access to the waste. The second stage will remove the waste.

WRAC-6.4 Waste Location and Removal Operations

The waste removal will be performed in discrete operations depending on the anticipated level of radioactivity. The waste will be removed by mining the area where the waste was emplaced. The mined waste will be transported to the packaging areas. The waste can be removed many ways using standard equipment. Section WRAC-7.2 contains a brief description and describes the feasibility of using various mining techniques for waste removal. An appropriate level of radiological controls will be used depending upon the radioactivity of the mined waste.

WRAC-6.5 Closure and D&D of the Facility

After waste is removed from the repository, the facility will be decommissioned according to the current regulations at that time.

WRAC-7.0 Removal Implementation

To support the requirement that waste removal is not precluded, a system for waste removal is described using available mining technologies. This description includes standard shaft sinking practices and drift excavations. Since the salt is a good radiation barrier, standard mining techniques may be used until contamination or radiation is reached that exceeds the current personnel safety limits. In these contaminated areas, currently available remote controlled mining equipment or equipment modified with off-the-shelf systems may be used. Where practical or necessary, removal operations will be performed remotely. All support, radiation and air quality monitoring, and geotechnical surveying will be performed remotely in the contaminated areas. The clean and contaminated areas will be segregated from each other and maintained using separate air intake paths and ventilation control structures.

The excavated waste and materials will be placed in appropriately designed waste containers. Appropriate air locks and bag out operations will be used to limit container contamination. The container surfaces will be decontaminated if necessary prior to being transported aboveground. Aboveground facilities will include a control center where any necessary remote waste handling and packaging operations are coordinated, and a decontamination area where waste containers will undergo any necessary additional decontamination or overpacking. The waste containers (including overpacks) will be staged aboveground for transportation. A control center in the underground will provide the interface between the aboveground control center and the underground operational activities.

The mining and waste removal operations will be designed to reduce the amount of contamination and exposure to allow limited human access for assessments, equipment retrieval, and equipment repairs. Operations will be designed to reduce human involvement to the extent practicable. Radiological work will be performed using standard industry practices and approved procedures.

The mining operations will use standard equipment to sink the shafts and excavate the drifts and support rooms. After the underground support areas are completed, the waste will be removed. Smaller scale mining equipment will be used to perform the removal. Modifications to the equipment will enable the vehicles and support equipment to be remotely monitored and controlled. The length of time since disposal will determine whether or not the RH-TRU and CH-TRU wastes will be retrieved in separate operations. It is currently anticipated that the radioactivity level of RH will decay to CH levels within 300 years after disposal (DOE 1995). Thus if removal is conducted subsequent to 300 years after disposal, a single mining operation may remove CH and RH simultaneously. However, removal prior to that time may require separate waste handling and packaging operations. Because RH wastes may pose a greater radiation hazard, RH-TRU removal activities may be more complex and possibly involve remote handling equipment in order to limit the exposure to personnel. RH-TRU waste should be removed in as intact a condition as possible. Some RH waste has been emplaced in shielded containers with the CH waste. These containers may require special consideration during removal. To aid removal operations, archived records will contain waste stream information, container type and location of the waste containers. The various types of waste containers will degrade at different rates due to their material composition and mechanical properties. Some containers, such as the pipe overpacks, have thicker containers walls than other containers and are expected to endure longer than less robust containers (container types are shown in Figure WRAC-5). Depending on the amount of time after closure the waste is retrieved, some containers may be more intact than others.

The preamble to 40 CFR Part 191 states that waste removal must be feasible but would likely incur great cost and overall occupational hazard. No time limit is specified. The removal approach will include measures that reduce the overall hazards but will require a long time period to complete. No time limits or cost estimates are included in this study.

The removal requirement states that removal of most of the waste will not be precluded but does not quantify the term most. This study assumes that the quantity removed shall be the amount that can be removed practically. No quantitative figure for this amount is specified because removal is speculative. The amount that practically can be removed using the technologies available at the time of removal shall be achieved. Since today's equipment is very effectively used to mine materials deposited millions or billions of years ago, this same equipment technology would provide for the feasibility to remove the waste any time during the regulatory time frame.

WRAC-7.1 Planning and Permitting (P&P)

The need to remove the waste would initiate the planning and permitting phase. By definition (40 CFR § 191.02[l]), waste removal does not occur until after disposal. The permitting requirements will be based on governing regulations at the time removal is authorized. The planning and permitting program will identify all required permits. This program will also research the available technologies to determine the appropriate removal techniques, the waste conditions, and the repository conditions (see Chapter 6.0 of the CCA for performance assessment assumed conditions after repository closure). After the initial research is completed, a plan will be drafted to itemize and schedule all removal activities.

The following considerations would be included in the planning and permitting process for the WIPP. These are necessarily general since the actual activities are solely dependent on the conditions at the time removal is deemed necessary. It should be noted that technologically, removal could be accomplished without any of the steps in this section. Such brute force approaches would meet the requirement of describing feasible techniques for removal; they are not, however, considered to be prudent.

Availability of Records. Available records will be collected to determine the location of waste containers, the nature of the waste placed in the facility, the underground excavation conditions during operations and at the time of closure, the location of seals and panel closures, and the amount and nature of backfill materials. Since the DOE plans to place records in numerous locations, records should be readily available for needed evaluations. Additionally, WIPP will also have complete inventories of the contents and locations of both the CH and RH containers.

Location of the Site. Records and markers will be used to identify site locations such as the previous shaft locations, the area of the disposal region footprint, previously drilled boreholes, location of monitoring activities, and other features that will aid in delineating the areas for new excavation and new surface structures.

Background Environmental Conditions. A baseline of environmental conditions will be established prior to any surface disturbing activity in order to get an accurate assessment of pre-operational conditions. Background measurements will be compared with environmental data stored in the site archives to determine any changes in conditions since the closure of the facility.

Time Since Disposal. This will be used to determine the expected condition of the disposal rooms, the amount of radioactivity and hazardous constituents that need to be dealt with, the amount of migration outside the disposal zone that may have occurred, and the presence of potential hazardous conditions such as pressurized gas and brine.

Facility Design. Initial facility designs will be prepared so that appropriate technologies can be identified and so that environmental impacts can be assessed. Release and exposure pathways will be identified and risk analyses performed to ensure appropriate environmental protection measures are taken. Design will be in accordance with applicable commercial and regulatory standards in effect at the time. Regulations such as those promulgated by the Occupational Safety and Health Administration and the Mine Safety and Health Administration will be given due consideration in designing systems that are protective of human health and the environment. Final facility design will be appropriately reviewed and approved by the implementing agency and appropriate regulatory organizations.

Permitting. Current environmental regulations governing releases to environmental media and protection of the public from exposure to noise, gases, dust, hazardous waste, radioactivity, and other potentially harmful substance will be identified and appropriate permits studies and impact statements will be obtained in the time frames dictated by the regulations.

Radiological Controls. The removal process will require a comprehensive assessment of the facilities and the precautions necessary to ensure the safety of workers and the public during the entire removal operation from initial coring until final closure and decommissioning of the facility. The facilities will include appropriate areas for washing and decontamination of containers and equipment and separate areas for the decontamination of personnel should such requirements arise. Decontamination areas and washing areas will be designed and constructed both in the underground and on the surface. Special areas will also be constructed on the surface and in the underground for storage of material and/or containers having high radiation levels. Such areas will be shielded to permit operational activities nearby without undue risk to personnel. Rigorous radiation and hazardous material monitoring of all activities from initial borehole drilling and coring to actual removal will be required until such time as removal activity experience provides sufficient information to understand the actual conditions existing in the repository and permit formulation of appropriate monitoring policy.

WRAC-7.2 Aboveground Setup and Shaft Sinking

Existing geological characterization data will be supplemented with new characterization data at the site. During all boring, shaft sinking, and mining activities in the vicinity of the waste panels careful monitoring will be conducted to ensure early determination of the presence of any hazardous or radioactive material. An initial shaft location sufficiently distant from the waste will be identified and excavated. Coring in the vicinity of the repository horizon will be performed in order to identify horizons that may contain radioactive contamination caused by brine migration through marker beds. The level of contamination will be assessed and appropriate precautions taken to protect personnel, the public, and the environment from contamination. Such precautions are used today in cleanup activities in which contamination is kept within well-defined barriers and entrance and egress is carefully controlled and monitored. Emphasis will be placed on avoiding the areas that were originally mined for the repository. The DOE currently believes that, for the WIPP, the best approach to the waste is from the south because this area avoids the existing shafts and mined areas.

Use of the intact portion of the formation instead of using previous shafts and tunnels minimizes potential ground control problems. Additional geological studies would be conducted to determine the adequacy of the rock south of the repository.

Aboveground support buildings will be constructed to house the exhaust fans and any radiation control equipment such as HEPA filters, administration facilities, operations and engineering offices, training facilities, safety facilities, maintenance support facilities, control center, waste staging and decontamination areas, loading/shipping docks and warehouses (waste containers and maintenance), laboratories and others as deemed necessary. Portable and/or temporary structures such as trailers could be used for miscellaneous activities. Power and water distribution network shelters will be required.

Where practicable, aboveground support facilities should be designed for later disassembly and removal to facilitate decommissioning. Removal facilities would closely resemble those currently in use at the WIPP and described in Chapter 3.0 of the CCA with some additional radiological control facilities and decontamination facilities.

A shielded area for the protection of personnel from higher levels of radiation, similar in construction to the shielded storage room currently located in the Waste Handling Building (see Appendix D&D of the CCA), may be required to handle and store the RH-TRU canisters and their containers prior to off-site shipment. This area will contain all the equipment necessary to transfer the RH-TRU waste into suitable waste containers and load shielded shipping casks. If necessary, remote operations can be used for any removed waste that exceeds CH-TRU safe handling limits.

Security fencing will be required around the facilities. The extent of the security devices required will be governed by the regulatory requirements at that time.

A control center will be located aboveground that houses the personnel and equipment that controls the remote mining equipment and all other remote operations.

At least three shafts will be constructed. The number and size of the shafts will be based on waste removal throughput requirements, airflow requirements, and mining regulations at that time. The underground ventilation requirement should be lower than the original ventilation system assuming a reduction in both manpower and diesel equipment usage (if used). To reduce the discharge of hazardous and radioactive particulate contamination, the removal working area and packaging areas will be provided with separate HEPA filtration systems. This precaution will reduce migration of particulate material from the mining areas.

The three shaft concept would include two intake shafts and an exhaust shaft. The current WIPP shaft designs would be adequate, although technology improvements may make operations more efficient and reliable.

Each shaft will include a hoisting system. The waste handling shaft (WHS) and hoist will be fully enclosed and will allow air intake without backflow. The WHS will be an air intake shaft that ventilates the maintenance, packaging, and contaminated work areas of the mine.

The ventilation exhaust system for the removal of the waste will be significantly more complex than the system supporting waste emplacement. Because of the likelihood of the production of hazardous and radioactive particulate material during the remote removal of waste material, the ventilation system will require local systems within the underground that include the appropriate exhaust fans, monitoring, and HEPA filtration systems used to filter the exhaust air during removal operations. The levels of dust in a potentially highly contaminated environment will present a significant maintenance challenge. Maintenance of these systems will require high degrees of redundancy of system components, system configurations, or flow paths. Flexibility of operation will be a major operational requirement of the ventilation system design in order to ensure that removal operations remain within the regulatory and safety limitations imposed for workers and the general public.   The system design must permit remaining within the allowable limits at all times. Since the potential for hazardous or radioactive material contamination will exist, once waste removal begins, filtration of all exhaust air will be required. Self-cleaning or roughing pre-filters may be used to increase HEPA filter life and reduce down time for filter change-out.

After the first shaft (no particular order) is completed, the others may be excavated from the bottom up using a drill and ream system similar to the system used at WIPP to excavate the existing air intake shaft. This will require access entries (drifts) to be excavated to the base of each shaft and drilling to this area. An ore transfer station will also be installed to facilitate removal of excavated salt (uncontaminated) from drift and support area mining.

WRAC-7.3 Underground Excavation and Facility Setup

After the shafts are completed, drifts will be excavated using commercially available equipment such as continuous miners, roadheaders, scalers, and ventilation paths will be established using air control regulators. Support rooms for use as maintenance areas, control rooms, and packaging areas will be excavated. Air locks will be constructed to isolate the clean areas from the contaminated areas by use of differential pressure. All equipment required for removal, packaging, and related support activities will be installed.

Excavation will be in two phases. The initial excavation will not contact waste but will mine support rooms and haulage drifts that provide ventilation and access to the waste panels. A barrier pillar will be maintained. The size of the barrier pillar depends on the anticipated conditions in the waste panels. The barrier pillar will provide protection from blowout or flooding due to pressurized gas or brine. The second phase will remove the waste. Conceptual layout of removal operations is shown in Figure WRAC-7.

Air locks will be used to allow travel between air circuits while maintaining the isolation of contaminated areas from the clean areas. Lined sumps may be used to manage liquids if conditions involving flowing brine are encountered.

The following support areas may be required:

Control Centers. Rooms that contain the remote control support interface between the surface control center and the equipment supporting the underground ventilation, mining, packaging, and transportation operations.

Maintenance Rooms. Shop areas where all maintenance and repairs are performed, including wash bay and parts warehouse for support equipment.

Personnel Support. Lunch room, lockers, washrooms, and facilities.

Container Warehouse. Storage for clean, empty waste containers, and decontamination supplies.

Packaging Area. Waste emplacement into containers, container filling, and container sealing area.

Decontamination Area. Container radiation survey and decontamination area.

Ore Transfer Station. Virgin salt transfer and removal station at base of shaft.

Container Staging Area. Lower hoist loading area with staging area (clean area) located in clean intake air feeding contamination area; final radiation survey area.

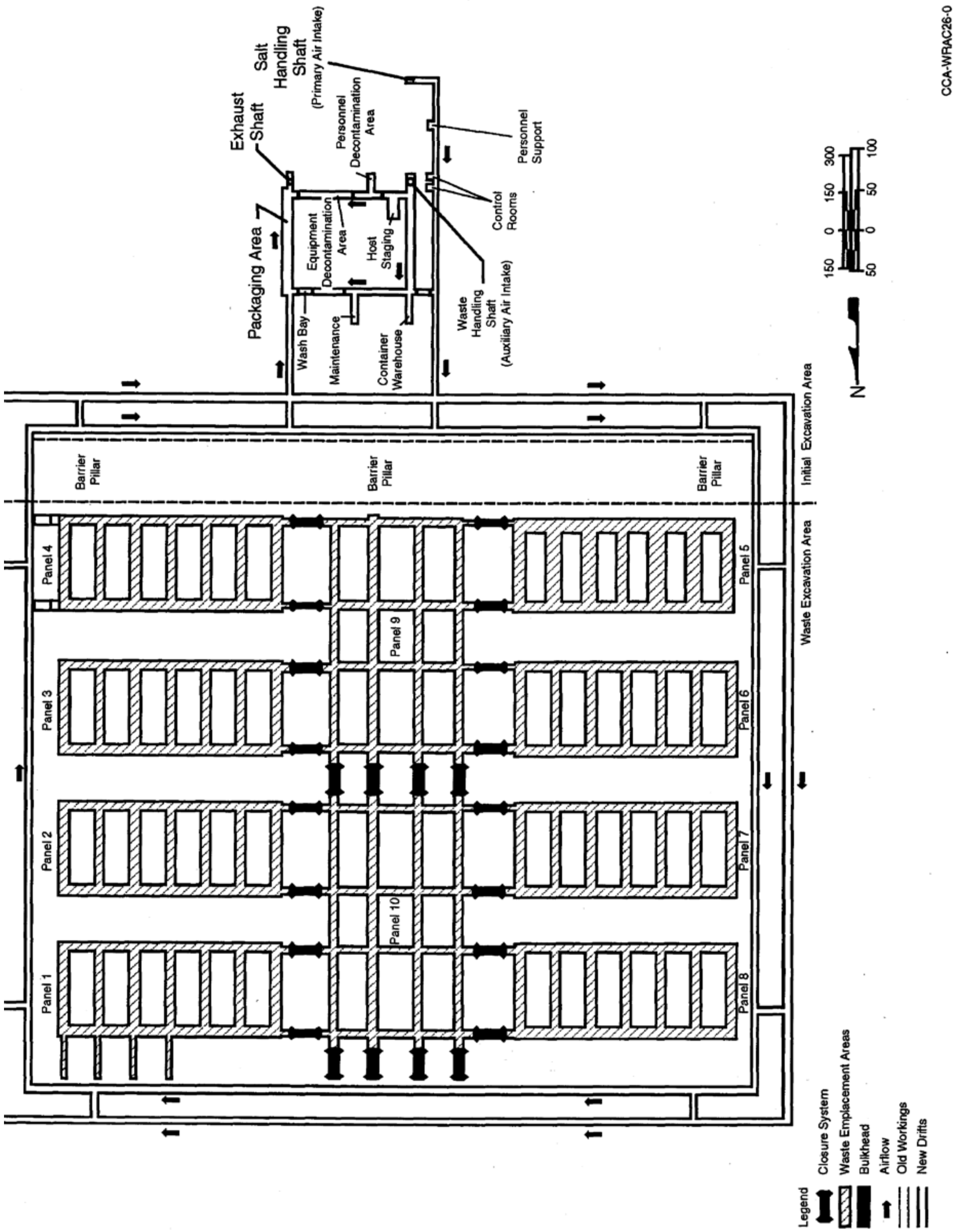

Figure WRAC-7. Repository Removal Operations Layout

WRAC-7.4 Waste Location and Removal Operations

A single drift should be excavated around the waste panels. This drift will provide ventilation that will be used during removal operations. After the support, ventilation, and access drifts are completed, the first panel can be entered to remove the waste. Panel 9, the panel closest to the exhaust shaft should be excavated first to reduce initial contamination. An entrance and exit will be excavated, dust and moisture control systems installed, and isolation bulkheads erected. The location of the panel closures should be available from the detailed information at record centers and archives. To determine the relative position of the waste, ground penetrating impulse radar technology could be used. Impulse radar technology has been successfully tested in salt mines and has demonstrated the capability of locating metallic targets up to ten meters away (Cook 1982). Other geotechnical techniques that identify variations in the host rock (such as sonic velocity or electromagnetic measurements) could be used to distinguish previously mined areas and potentially the waste. The access entries could be completed and the entrances to each panel could be located by the panel closure systems and radar. Radar and gamma detectors could be used to help locate the RH-TRU waste. The gamma detectors should be effective during the first few hundred years after disposal prior to extensive decay of the RH radioactivity.

Initially, each waste panel will be evaluated using a small diameter probe hole drilled from the access drifts. The hole will be used to investigate the conditions within the panel. Of particular interest will be the porosity (degree of consolidation), pressure, and moisture content. In addition, gasses will be tested for explosive or flammable constituents.

For conditions that would require the CH-TRU and RH-TRU waste removal operations be performed in separate operations, the CH-TRU waste will be removed by mining the area where this waste was emplaced. The CH-TRU waste and surrounding rock will be removed and transported to the packaging areas without disturbing the RH-TRU waste. The RH-TRU waste will be removed by excavating the rock salt around the waste and removing it in as intact a condition as possible. This waste may be placed in a waste container at the work face and then transported to the packaging area. The waste container may be the shipping container if sealing and decontamination are possible underground or it may be over-packed at the packaging area prior to decontamination.

The CH-TRU waste can be removed many ways using standard mining equipment. The waste could be mined out using large-scale continuous miners such as those used to originally mine the underground excavations. However, this method does have the potential to spread excessive amounts of particulate contamination and could be difficult to control particularly with respect to the RH-TRU wastes. A more practical approach would be to use small-scale mining equipment such as road headers, scalers, hydraulic breakers, small loaders, and excavators. A small head continuous miner or a roadheader (telescopic boom miner) could be used to excavate a large portion of the waste. The other extraction equipment would be used to remove the most difficult waste such as large metallic items.

A practical approach to CH-TRU removal is to excavate an area approximately three feet high directly below the waste and then, using a hydraulic breaker/scaler system similar to the Fletcher diesel powered scaler capable of being equipped with either an Alpine No Gap cutting head, a percussion scaling hammer, or a scaling claw attachment devices to dislodge the waste above.

Similar scaling devices have been successfully utilized at WIPP and other mines in the Delaware Basin. Appendix WRAC, Section 6 of the CCA detailed specific mining equipment discussed above (DOE 1996).

The CH-TRU waste will be excavated behind bulkheads separating the mining area from normal ventilation. After removing a predetermined amount of excavated materials, loaders will transport the waste materials to the packaging area.

The CH-TRU waste will be transferred to the waste handling and packaging system which packages the waste into containers. Bulk material handling equipment may be used to transfer the waste from the loaders to the waste containers. The container will move into the decontamination area where it is automatically surveyed and decontaminated. The container is then moved into the hoist underground staging area where it is surveyed again and transported to the surface. The container will be warehoused until transported off site.

The CH-TRU waste containers will be selected using the regulatory requirements at that time. Currently available containers will be researched to determine their suitability, and if none are found, new containers will be built and certified.

An aboveground decontamination area will be used if any contamination is found during the off-site container loading and transportation operations.

RH-TRU waste will be removed after the CH-TRU waste is excavated past the shield plugs to allow equipment access. The equipment will be set up to remove and excavate the materials around the waste. The waste will be loaded into a container and moved to the packaging area.

There, the container may be decontaminated, if possible, or overpacked prior to shipment aboveground. After completion of any necessary decontamination, the RH-TRU waste will be transported to the surface and then warehoused in a shielded area prior to off-site shipping. Radiation surveying and decontamination procedures will be similar to the CH-TRU operations.

The waste will be removed from the panel and its original access entries. After the initial panel's waste is removed, all other panels will be excavated.

If the removal of waste is not initiated until hundreds of years after disposal and the RH radioactivity has decayed to near the activity levels of the CH waste, the decision may be made to remove the RH waste in conjunction with CH waste removal. Under these conditions, evaluation of the probable condition of the RH containers should be made. The heavier wall thickness of the RH containers may provide an opportunity to remove the RH waste intact provided that corrosion has not yet destroyed the containers' integrity. Under these conditions, RH removal should be conducted in a manner similar to that described above. That is, CH removal within a given panel should proceed until sufficient clearance is obtained to permit installation of equipment to excavate the rock salt around the RH container and then remove the container in as intact a condition as possible. Under conditions in which the RH container has lost its integrity, removal of RH waste would be accomplished using the procedures applicable to CH waste removal.

WRAC-7.5 Closure

After the waste is removed from the repository, the facility will be decommissioned in accordance with the regulatory requirements applicable at that time. Closure may include partial backfilling of the mine and support areas. The mine may be used for disposal of both contaminated and uncontaminated muck. The shafts will be sealed (see CCA Appendix SEAL for the details of what a seal may look like) and the surface facilities will be decontaminated and decommissioned (see CCA Appendix D&D for an outline of a decontamination and decommissioning program). All decontamination wastes could be packaged and shipped in the same fashion as the removed waste.

WRAC-8.0 Currently Available Removal Technologies

As part of the feasibility demonstration, the DOE has identified technologies that are available today that could be used to facilitate removal. These are divided into mining technologies (Section WRAC-8.1) and remote removal technologies (Section WRAC-8.2).

WRAC-8.1 Mining Techniques for Waste Removal

Waste removal can be accomplished in many ways using available technologies. Mining techniques are the most plausible since they must be used initially to provide access to and locate the waste. Methods used to extract salt and potash were briefly evaluated to determine the capable removal techniques. Since the waste is hazardous and radioactive, the techniques used must limit the spread of contamination to the environment and exposure to facility personnel. The condition of the waste at the time of removal will be unknown and is related to the amount of time the waste was exposed to repository conditions.

Removal processes should be performed with as little direct human interaction as possible. Limited contamination is acceptable provided that the exhaust from these areas is controlled and filtered. Roughing filters and HEPA filters can be used to control contamination. Limiting the air throughput in the work areas will minimize the spread of contamination.

Mining techniques that were evaluated include the following:

- continuous mining,
- drill and blast,
- solution mining and mechanical extraction, and
- mechanical excavation techniques.

WRAC-8.1.1 Continuous Mining

Continuous mining was used to excavate most of the WIPP facility. A continuous miner is used to mechanically excavate materials by ripping, milling, or boring the rock from the work face. Rotary drums and heads with cutting bits attached to the surface cut the rock. The miner mechanically removes the loose material and transports it away from the face onto a conveyor where it can be transferred to haulage equipment or transported by belting to other areas. Continuous mining equipment can precisely remove rock and hold tolerances in the order of a few inches. The equipment is available in a wide variety of styles and sizes. Remote controlled continuous miners are commercially available from manufacture such as Joy, Caterpillar and Bucyrus.

The waste contains some metallic items (for example, cadmium, lead, silver) and the containers are steel. Continuous mining heads can be made with bits utilizing various steel alloys. Examples of these alloys include high-strength low alloy (HSLA) ordnance-grade steels such as AISI 4140 chromium molybdenum steel and AISI 8650 nickel chromium molybdenum steels; molybdenum or tungsten-based high speed tool steels such as M2 or T6; and the powder-metallurgy-produced sintered tungsten carbide steel groups such as the six percent cobalt group 2 alloy. All of these alloys are frequently used for various mining, petroleum production drilling, ordnance, and tooling applications such as drilling, mining, and cutting through metals, ores, and hardened rock. The equipment may be further modified by changing the cutting head configuration and sizing to efficiently handle the metallic substances by altering the cutting surface, speed, and bit angles. The need to address cutting through metals, particularly the metal containers, will be dependent upon the time after disposal that removal is initiated (see CCA Chapter 6.0 for performance assessment assumptions regarding metal persistence; DOE 1996).

Large-scale continuous mining of the waste is possible but is impractical because of the potential for spreading contaminated material. Excessive amounts of dust are generated during continuous mining. Water is generally used for dust control which may increase the spread of contamination. Water will transport the contamination into the fractures of the surrounding rock.

Small-scale continuous mining of the waste is practical if electric equipment is used and the area is isolated during mining operations. To control contamination, bulkheads can be placed close to the mining face that isolates the mining activities from normal mine ventilation. Ventilation in the mining area can be reduced or eliminated since remote controlled electrical equipment would be used and no diesel equipment or personnel are required. Suspended particles can be effectively removed from the air during mining and loading operations using local HEPA filtered systems with prefiltering capability to reduce the maintenance of HEPA filters.

WRAC-8.1.2 Drill and Blast

This method excavates by drilling holes in a rock face and filling the holes with explosives. The explosion fractures and loosens the rock material. Other equipment is then used to remove the debris and the cycle starts again.

This method could also be used to remove the waste. However, this method generally requires personnel to drill and load and would be difficult to perform remotely. The dust and fumes caused after the explosives are detonated must be ventilated and would cause a contamination problem. Isolating the working areas with bulkheads would be difficult because of the large pressures produced by the blast. Thus, while this method could possibly be used to remove the waste, the associated problems of personnel in the vicinity, ventilation, contamination, and blast side-effects make this method impractical.

WRAC-8.1.3 Solution Mining

Solution mining uses a solvent to extract the material of interest. In salt solution mining, water is injected into the formation and saturated brine is pumped out.

A modified version of this technique could possibly be used to remove the salt from around the waste at the repository level. After the salt is removed, remote controlled mechanical equipment would remove the exposed waste. Hence, both standard mechanical mining methods and solution mining would be required. However, this method would require large amounts of water and would require a system to be designed to recycle the water. Water treatment would also be required to extract salt and any contaminated material. These processes involved add significant complexity to the system and the salt, and probably the water, would still be contaminated and would have to be packaged along with the waste. Additionally, this method would produce a large volume of contaminated material and would spread contaminants into the fractures of the surrounding rock. Therefore, based on the problems of the systems' complexity and of the likely ineffectiveness of those systems, in general, this method is impracticable.

WRAC-8.1.4 Small Scale Mechanical Excavation Techniques

Smaller-scale mechanical excavation techniques can be used and are the most favorable. One method uses roadheaders, hydraulic breakers, and scalers to dislodge material from the face by scaling or cleaving the material. This method is extremely slow and precise. It produces the least amount of dust and can be performed remotely.

Additionally, other forms of mechanical excavation equipment such as skid-steer loaders with various small backhoes, manipulators, and earth moving and cutting attachments exist and would also be used to dislodge, move, cut, and crush the waste. These types of equipment will be required to support any method used.

WRAC-8.1.5 Remote Mining

Two examples of remote mining operations include work in Australia and France. Australia removed 198,334 tons of coal from a McQueen Company mine using a remote controlled flexible conveyor train, a continuous miner, and roof-bolting machines between 1985 and 1987 (McQueen 1988). The French have been actively pursuing remote coal mining since 1972. In 1983, 93 percent of French coal shearers were remotely controlled and monitored (Boutonnat 1986).

In 1986, the U.S. Bureau of Mines initiated research to develop technology to enable the relocation of workers from hazardous areas (Schnakenberg 1993). Such work includes developing computer assisted operation of continuous miners, roof bolters, and haulage systems (Schnakenberg 1993).

In addition to remote mining techniques, mining has included automation to increase productivity and reduce human resources in remote or high hazard mines. Recent mining has been performed using autonomous load/haul equipment. Such techniques are used in Australia by Rio Tinto Ltd. in their iron ore operations (Rio Tinto 2015). This technology has been successfully used along with other remote techniques at this mine since 2008. Autonomous technologies have also been used in other mining operations in Chile, Australia, Queensland and the United States (Brundrett 2014).

Remote and automated mining technologies are continuing to progress making the likelihood of their success in any future removal operations highly probable.

WRAC-8.2 Remote Removal

On April 27, 1992, a retrieval demonstration took place that successfully retrieved SWBs from a WIPP storage room. This demonstration simulated a cave-in or roof fall condition with salt and metal roof support materials piled on top of the SWBs. All retrieval operations were performed using remote controlled equipment.

The equipment used for this demonstration consisted of two remote controlled skid-steer loaders, a remote controlled freestanding portable television camera, a WILD TM 3000 automatic laser survey station, a portable beta-gamma radiation detector, and an ANDROS Mark VA hazardous duty robot. One remote-controlled skid-steer loader used a backhoe attachment and the other used a manipulator, front loader bucket, hydraulic breaker, or grapple bucket attachment. The attachments were changed out when required. The equipment used both radio and tethered cable remote control methods.

The demonstration used the robot to survey the areas using television cameras and laser ranging equipment. The condition and location of the SWBs were determined using the robot's data. The robot also set up equipment and surveyed the areas for radioactive contamination.

In order to remove the SWBs, the salt and metal materials were removed and boxed in containers using the remote controlled equipment. The SWBs were successfully removed from the room.

Although the retrieval demonstration was performed on a small scale, it proved that remote controlled equipment could be used to remove salt and metal materials from around a waste container, package the excess material, and remove the waste container. The removal of waste from a consolidated salt condition will involve a more complex set of circumstances. However, current technological capabilities permit remote operation of current equipment and will permit these complexities to be solved operationally. Thus, no new technology will be required.

Current technology exists and is in operation in mines throughout the world to excavate materials using remote controlled machinery. Remote coal mining has been performed for many years by countries including Australia, France, Austria, Canada, Russia, and the United States. Remote controlled continuous miners, rock bolters, drills, haulage, road headers, loaders, and locomotives are examples of the equipment used at these mines (Naunkovic 1986).

WRAC-9.0 Conclusion

The requirement for waste removal after closure originates in 40 CFR § 191.14(f). Specifically, 40 CFR § 191.14(f) states that WIPP disposal systems will be selected so that removal of the waste is not precluded for a reasonable period of time after disposal (EPA 1993). Removal of the waste after the repository is sealed is possible. Because access to the repository was accomplished using standard mining practices, access to the waste after closure can be accomplished using the same mining technologies supplemented by a more extensive use of remote controlled and robotic equipment. The degree of robotic and remote controlled technology required to successfully remove the waste is not only available but also has been used in mining and industrial packaging activities around the world. The accessibility for waste removal has no operational time limit assuming use of today's technology. 40 CFR § 194.46 states that the analysis of the technological feasibility of removing the waste use ". . .technology levels at the time a compliance application is prepared." Locating and removing the waste is feasible using currently available equipment modified to operate remotely. Packaging the removed waste and decontaminating the containers can be safely accomplished by using established techniques. The concept of sealing and decommissioning the facility will have been demonstrated prior to waste removal.

As stated in the preamble to 40 CFR Part 191, with respect to the waste removal requirement:

Any current concept for mined geologic repository meets this requirement without any additional procedures or design features. For example, there is no intent to require that the repository shafts be kept open to allow future recovery. To meet this assurance requirement, it only need be technically feasible (assuming current technology levels) to be able to mine the sealed repository and recover the waste - albeit at substantial cost and occupational risk.

The WIPP is a mined geologic repository and, as such, meets the removal requirement without any additional design requirements since current technology can be used to remove the waste if the need arises. Examples of the necessary mining equipment are in existence today, are readily available, and have been effectively used for mining applications. Thus, it is logical to conclude that since the necessary equipment not only exists in off the shelf forms but also has been effectively used in a variety of mining applications, then waste removal utilizing this equipment is feasible. Partial proof of this concept has already been demonstrated by retrieving waste containers from under salt and metal roof support materials using remote controlled equipment (DOE 1993).

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