Advancing the Science and Engineering Supporting Deep Geologic Disposal of Nuclear Waste in Salt: Objectives, Background, and Structure

Organized
by
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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

- Objective and Goals of Workshop
- Agenda
- Background
- Safety Case

Objective and Goals of Workshop

Objective

- Develop an RD&D Plan that will advance the bases for disposing of heat generating nuclear waste in salt
  - Plan will be based on input developed in this workshop, but developed post workshop
  - Plan will address research, development, and demonstration (RD&D) in the areas of field testing, laboratory testing, and modeling

Goals

- Identify a comprehensive set of RD&D needs and approaches to addressing them
- Elicit input to a decision-making framework that will be used to identify objectives of an activity and the relative importance of a proposed activity
  - Posed questions and evaluation criteria

Structure of Workshop

Wednesday Morning Plenary, March 6

0830 – 0845	Welcome and Purpose – Bob MacKinnon (SNL) and Bruce Robinson (LANL)
0845 – 0900	DOE Perspectives – Prasad Nair (DOE-NE), Mark Senderling (DOE-EM) and Roger Nelson (DOE-EM)
0900 – 1000	Workshop Objective, Goals, Structure, and Approach – Bob MacKinnon (SNL) and Bruce Robinson (LANL)
1000 – 1015	Break
1015 – 1100	Continue - Workshop Objectives, Background, and Structure – Bob MacKinnon (SNL) and Bruce Robinson (LANL)
1100 - 1200	Summary and Status of US Salt Repository Technical Basis - Christi Leigh (SNL), Don Reed (LANL), Jens Birkholzer (LBNL)

Structure of Workshop

<u>Wednesday Afternoon Breakouts, March 6</u>

1200 – 1315	Lunch
1315 – 1345	Structure and Goals of Breakout Sessions – Bob MacKinnon (SNL) and Bruce Robinson (LANL)
1345 – 1415	Instructions to Breakout Groups – Dave Sevougian (SNL)
1415 – 1700	Breakout Group 1: Post-Closure Repository System (EBS post-closure processes within the excavation and NBS post-closure processes in the host salt formation) Chairs – David Sevougian (SNL), Don Reed (LANL); Rapporteur – Dan Levitt (LANL) Breakout Group 2: Pre-closure Repository System (design, demonstration, and pre-closure issues) Chairs – Frank Hansen (SNL), Ned Elkins (LANL); Rapporteur – Ernie Hardin (SNL) MacKinnon (SNL) and Rob nson (LANL) will act as roving participants to ensure Pre-Closure/Post-Closure Integration.

Breakout Groups will:

- Review RD&D strawman issue list
- Propose additional issues/remove issues as necessary
- Define specific tests/modeling needed to advance the state of the art to address Post-Closure System issues and Pre-Closure System issues
- Input to decision making framework

Structure of Workshop

<u>Thursday Morning Session on Field Testing at WIPP, March 7</u>

0815 – 0900 Reconvene and Synthesis of Breakout Session results – Session Chairs and Rapporteurs

0900 – 0910 Introduction to Field-Testing Session –Bruce Robinson (LANL) and Bob MacKinnon (SNL)

0910 – 1145 Field-Testing Session

- 0910 – 0930 Summary of Past Field Tests Relevant to Disposal of Heat Generating Waste in Salt – Kris Kuhlman (SNL)
- 0930 – 1015 Underground Research at WIPP – Frank Hansen (SNL)
- 1015 – 1030 Break
- 1030 – 1115 Thermal Field Testing at WIPP – Doug Weaver (LANL)

1115 – 1145 Re-Entry into the North Experimental Area of WIPP – Doug Weaver (LANL) and Michael Schuhen (SNL)

1145 – 1300 Lunch

Structure of Workshop

<u>Thursday Afternoon Wrap Up, March 7</u>

1300 – 1500	Resume Field-Testing Session Define specific tests/modeling/path forward Input to Decision Making Framework
1500 – 1515	Break
1515 – 1615	Plenary on workshop summary and future actions – Bob MacKinnon (SNL) and Bruce Robinson (LANL)
1615 – 1630	Concluding Remarks – Prasad Nair (DOE), Nancy Bushman (DOE), Roger Nelson (DOE)

Background: Why Salt?

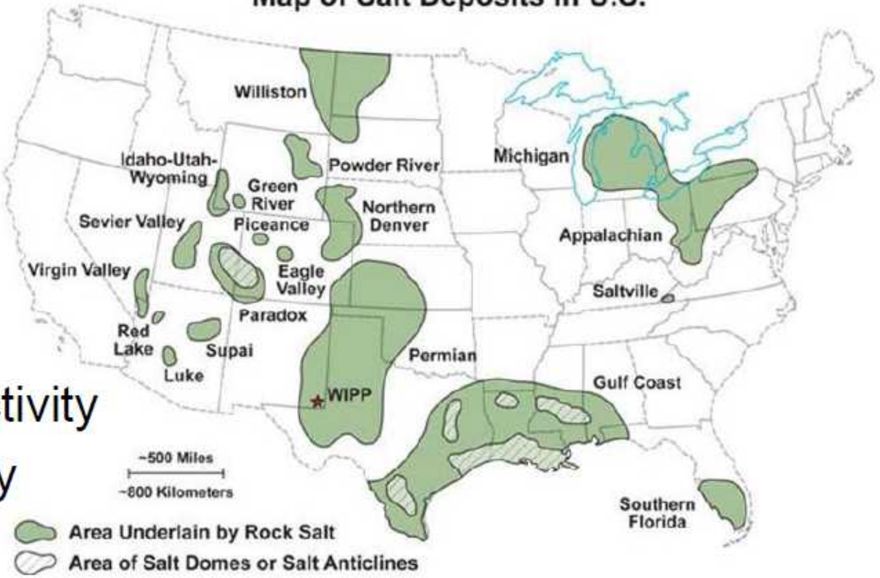
Why Salt?

- Salt was recommended by the US National Academies of Science & Engineering in 1957
- Salt has positive attributes for waste disposal
- Salt formations are plentiful and are widely distributed around the US
- Salt has been well characterized both within the US and Internationally (i.e., for waste disposal & for underground storage)
- Waste Isolation Pilot Plant (WIPP), a geologic repository for the disposal of US defense transuranic (TRU) waste in bedded salt, has been certified and has been operating for 12 years

Background: Salt Attributes and Distribution

Attributes and Distribution

Map of Salt Deposits in U.S.



SALT ATTRIBUTES

- Easily mined
- Deforms plastically
- Fractures self-heal
- High thermal conductivity
- Very low permeability and porosity
- Has existed underground for millions of years
- Deposits are often in stable tectonic regions and exist in many locations with geographic distribution in the U.S.

Background: Conceptual Repository Layout

Alternative Layout

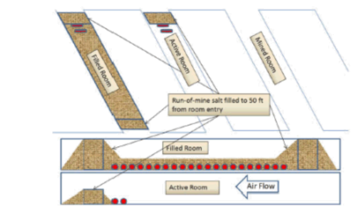
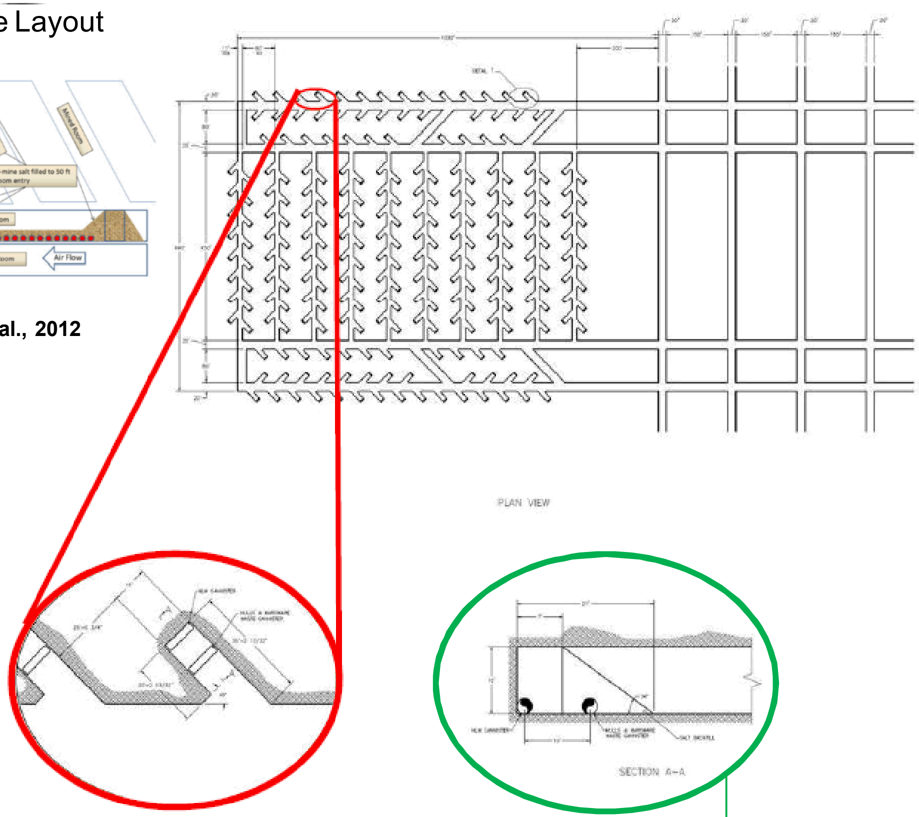


Figure 5-14 Room Closure Schematic

Carter et. al., 2012

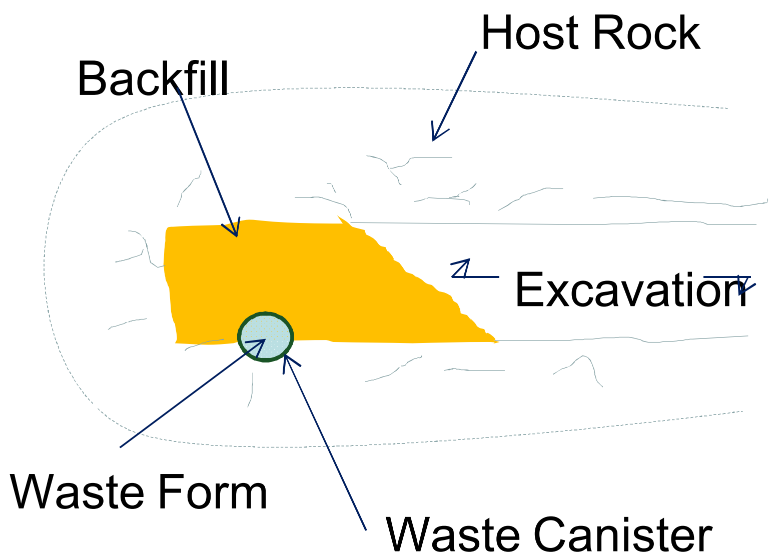


- Waste canisters may be placed either horizontally or vertically
- Canisters covered with mine run salt for shielding
- Placement of waste begins at one edge of a repository and progresses to the other edge staying ahead of the thermal pulse
- Narrow room and alcove widths and low extraction is desirable
- Mining layout is developed on the basis of thermal loading & mining experience

Next Slide

Figure from - A Generic Salt Repository for Disposal of Waste from a Spent Nuclear Fuel Recycling Facility. September 2008. GNEP-WAST-MTSD-MI-RT-2008-000245.

Background: Host Rock and EBS Barrier Functions

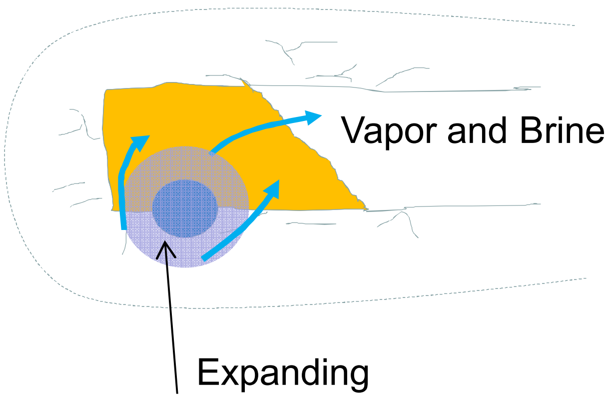


Expected or nominal evolution of the system will result in negligible radionuclide releases to the geosphere

Less likely events such as human intrusion might affect performance of the system

- The host rock is the most important barrier , interactions between the host rock and the backfill are of primary importance
- Due to the self healing properties of salt, excavations will creep towards closure and potential flow paths for brine and gas will be sealed under the action of the in situ stresses
- Creep closure is accelerated under higher temperatures
- To maintain the low permeability of the host rock salt fracturing of the host rock during convergence of the excavation should be avoided
- Excavations will be backfilled with crushed salt to stabilize converging host rock and limit excavation volume reduction
- Due to rock stress the backfill consolidates into a mass comparable to intact salt with low permeability
- In addition to acting as an impermeable barrier and stabilizing the host rock, the backfill conducts decay heat away from the waste container
- Waste Canister prevents water from contacting the waste and provides containment of the waste for an adequate period of time
- Waste Form limits the release rate of radionuclides subsequent to container breach

Background: Host Rock and EBS Barrier Functions cont.



- Low Thermal Loads – "WIPP Like"
- High Thermal Loads – Increase in the number of potentially beneficial and/or detrimental FEPs (e.g., increased drying, generation of acidic brine)

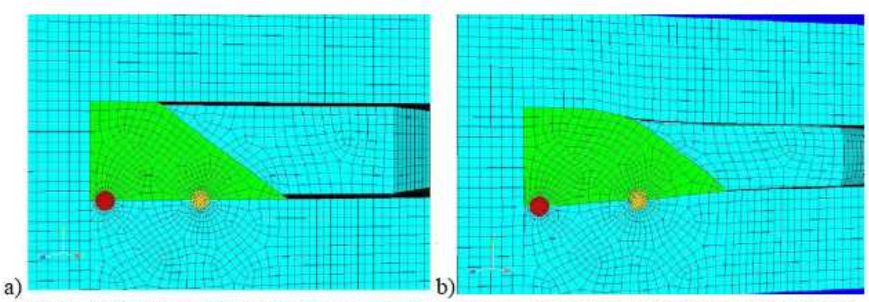


Figure 4.25. Alcove-scale thermomechanical case meshes at a) 0 years and b) 14 years showing grid deformations

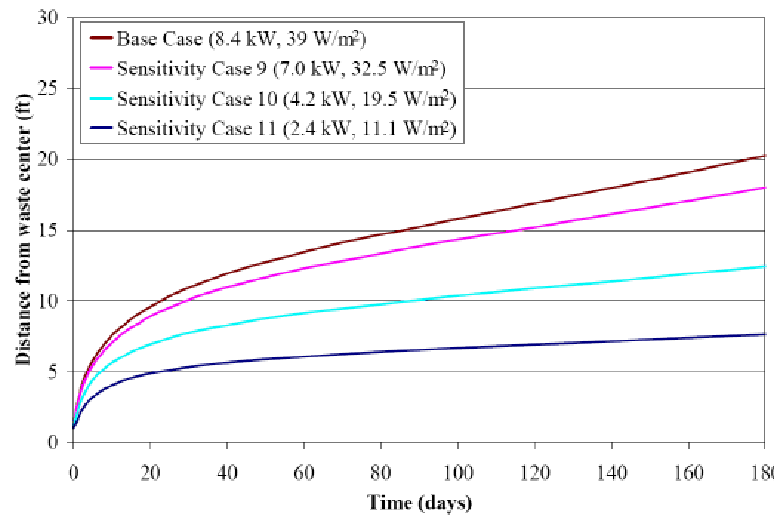
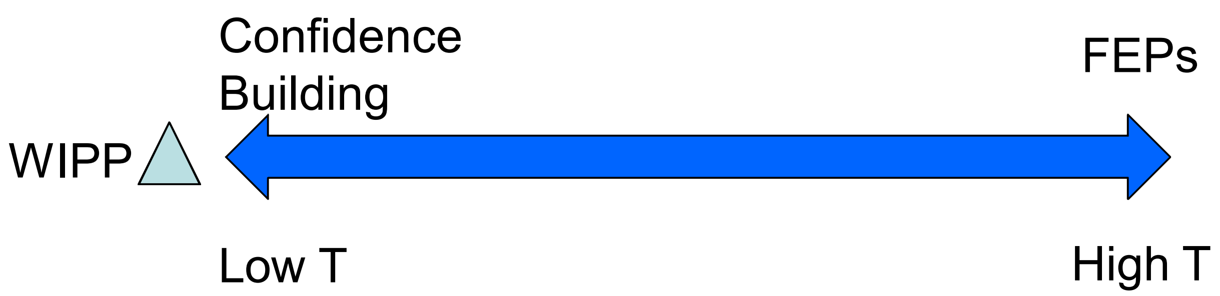


Figure 4.29. 38°C (100°F) thermal front migration for the Base Case compared with Sensitivity Cases 9, 10 and 11

Results from - DJ Clayton and CW Gable, 3-D Thermal Analyses of High-Level Waste Emplaced in a Generic Salt Repository, SAND2009-0633P, Jan 2009.

Background: Where should the focus be?

- Low Thermal Loads – “WIPP Like”
- High Thermal Loads – Increase in the number of potentially beneficial and/or detrimental FEPs (e.g., increased drying, generation of acidic brine)



Background: On-Going and Prior UFD R&D Activities

- UFD EBS R&D examined coupled THMC processes, lab testing and modeling, initiated in FY12
- Last March 15, DOE NE and EM reached an agreement on a set of high-level technical objectives and science-based scope of work – DOE, SNL, LANL, LBNL developed a R&D Plan
- Studies were initiated in May 2012, most are being continued in FY13

ACTIVITY 1: EXISTING SALT DATA COMPILATION AND ASSESSMENT
ACTIVITY 2: TEST PLANNING FOR RE-ENTRY INTO THE NORTH EXPERIMENTAL AREA OF WIPP
ACTIVITY 3: THERMAL, MECHANICAL, HYDROLOGIC, AND CHEMICAL LABORATORY STUDIES RELATED TO SALT

- **3.1 Hot Granular Salt Consolidation, Constitutive Model and Micromechanics**
- **3.2 Thermal Conductivity as a Function of Porosity and Temperature**
- **3.3 Laboratory Thermomechanical Testing**
- **3.4 Brine Migration Experimental Studies**
- **3.5 Study of Material Interactions In Heated Salt**
- **3.6 Study of Thermodynamic Properties Of Brines, Minerals And Corrosion Products In High Temperature Systems**
- **3.7 Radionuclide Solubility Measurements**

ACTIVITY 4: MODELING STUDIES RELATED TO SALT

- **4.1 Safety Framework Development**
- **4.2 Total System Performance Assessment (TSPA) Model Development**
- **4.3 Generic Salt Repository Benchmarking**
- **4.4 Thermomechanical-Hydrological and Chemical (TMHC) Model Development/Brine Migration**

ACTIVITY 5: INTERNATIONAL COLLABORATION
ACTIVITY 6: SALT INSTRUMENTATION DEVELOPMENT AND TEST METHODOLOGIES

Safety Case Structure for Organizing RD&D

- A *safety case* is an integrated collection of evidence, analyses, and qualitative and quantitative arguments used to substantiate and demonstrate the safety of a *system*

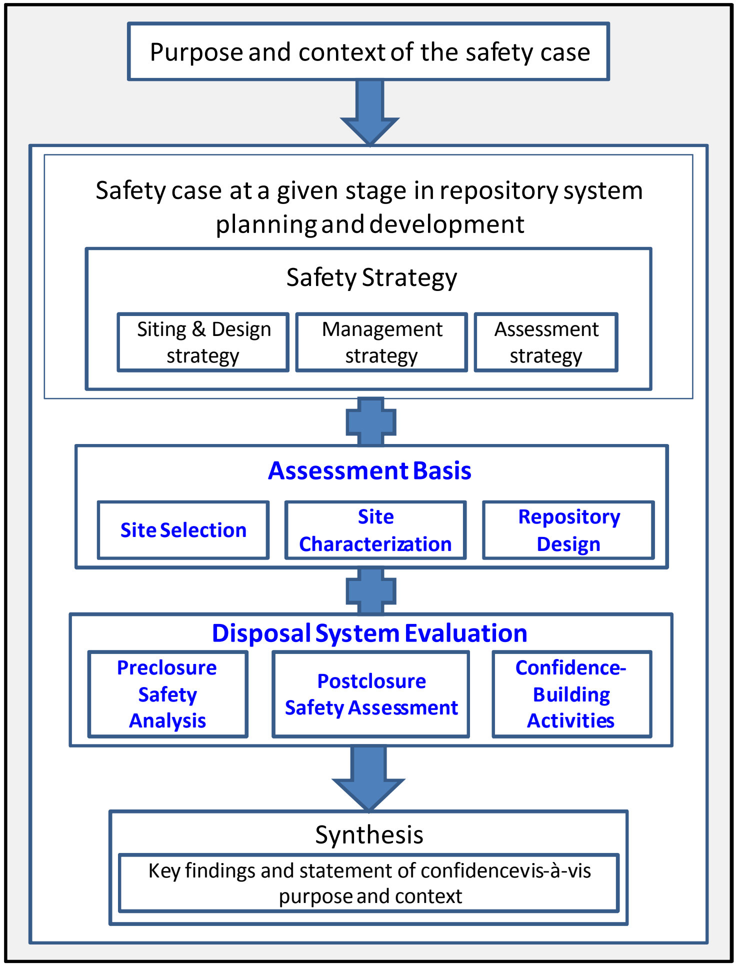
- A *safety case* provides the necessary structure for organizing and synthesizing existing and new knowledge and for prioritizing future research and development (R&D) activities

- Although it can be argued that the post-closure safety assessment is the most important element of the safety case, <u>*there are several other elements that are also important*</u>

Safety Case Structure for Organizing RD&D

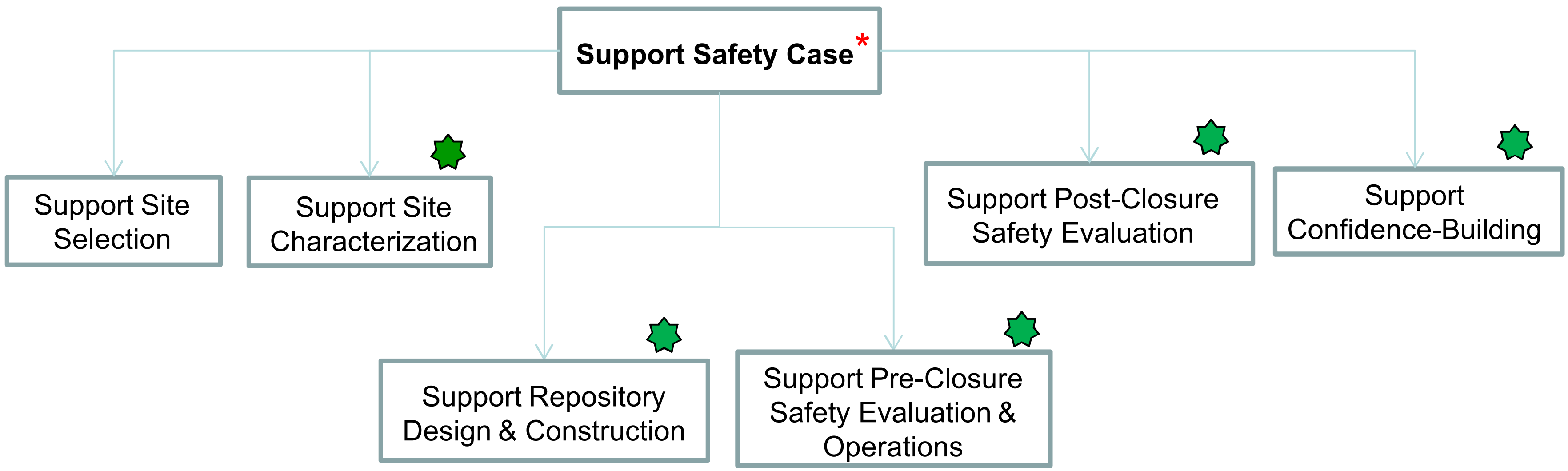
- Purpose and Context
- Safety Strategy
- Assessment Basis
  - Site Selection
  - Site Characterization
    - Natural Barriers
  - Repository Design
    - Disposal Concept
    - Waste Inventory and Waste Forms
    - Engineered Barriers
- Disposal System Evaluation
  - Preclosure Safety Analysis
  - Postclosure Safety Assessment
  - Confidence-Building Activities
- Synthesis of Findings
  - Statement of Confidence

modified from NEA 2004



Overview of the Elements of a Safety Case

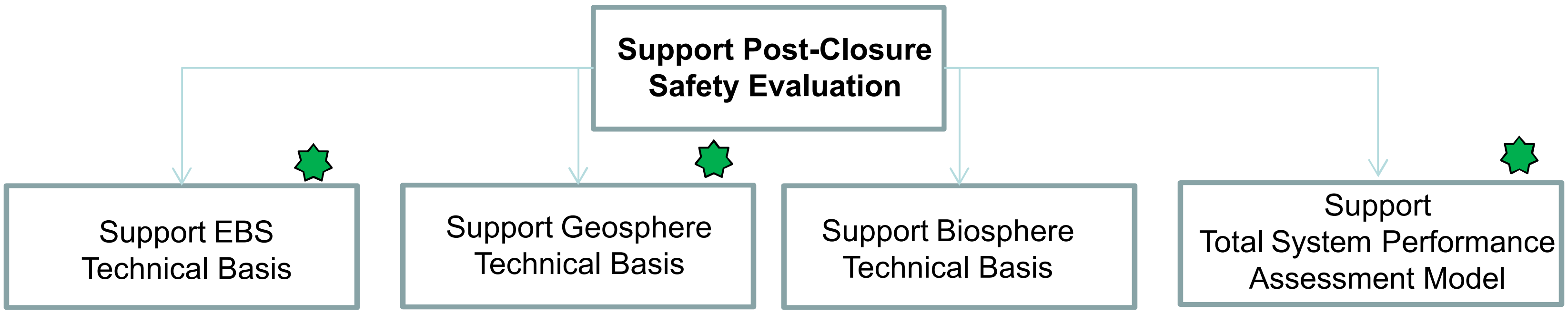
Safety Case Objective Hierarchy



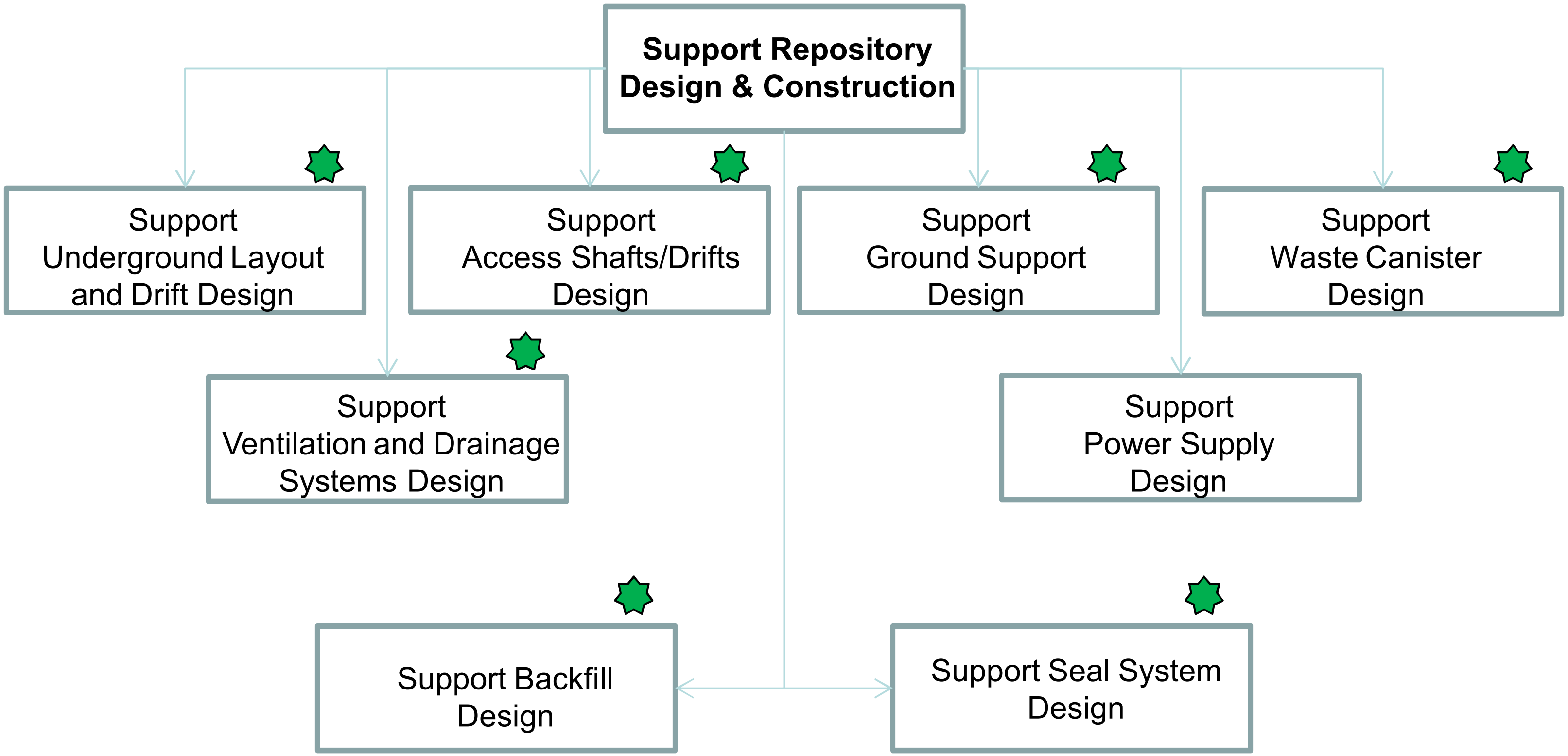
Indicates objective relevant to this workshop

* Safety case is for disposal of DOE-owned and commercial HLW/SNF.
(Note: Transportation system and waste receipt and surface facilities and operations are not included in this presentation.)

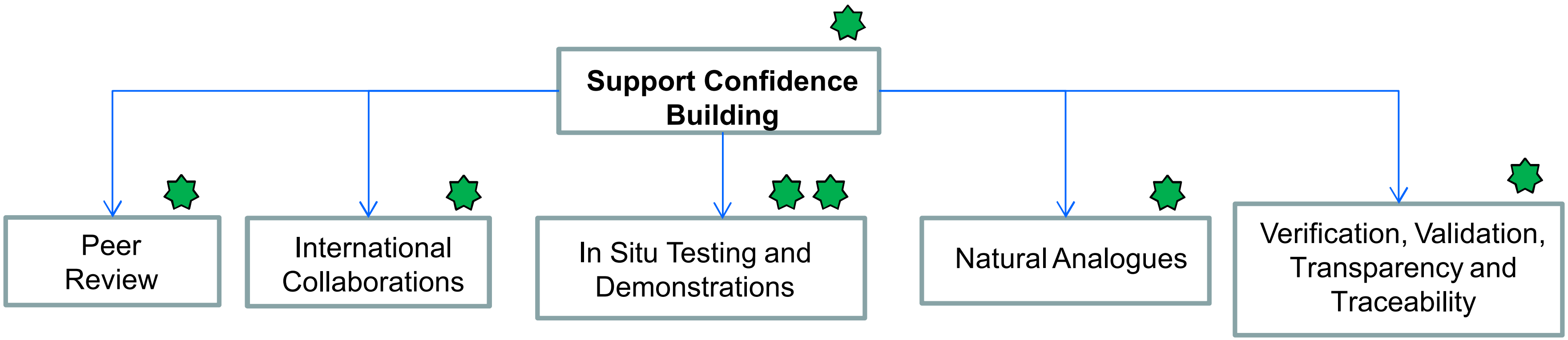
Safety Case Objective Hierarchy: Postclosure Safety



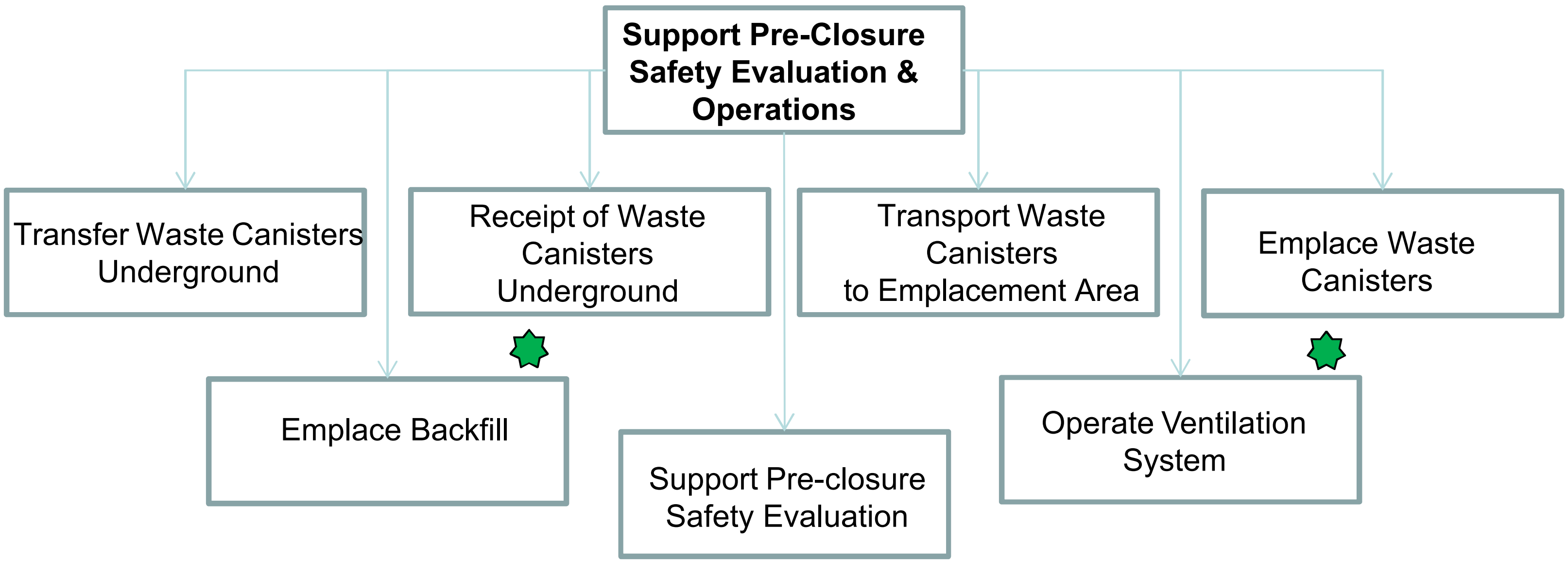
Safety Case Objective Hierarchy: Design



Safety Case Objective Hierarchy: Confidence Building



Pre-Closure Safety Evaluation & Operations Objective



What are you tasked do in this workshop?

This afternoon we will break into two breakout groups:

Breakout Group 1: Post-Closure Repository System (EBS post-closure processes within the excavation and NBS post-closure processes in the host salt formation) Chairs – David Sevougian (SNL), Don Reed (LANL); Rapporteur – Dan Levitt (LANL)

Breakout Group 2: Pre-closure Repository System (design, demonstration, and pre-closure issues) Chairs – Frank Hansen (SNL), Ned Elkins (LANL); Rapporteur – Ernie Hardin (SNL)

- Breakout Groups will:
  - Review RD&D strawman issue list
  - Propose additional issues/remove issues as necessary
  - Define specific tests/modeling needed to advance the state of the art to address Post-Closure System issues and Pre-Closure System issues
  - Input to decision making framework

What are you tasked do in this workshop?

Tomorrow we will work together as one group. The goals are twofold:

(1) Develop input necessary to design a successful thermal field test plan

(2) Develop input on potential additional research activities in the underground that would advance the state of the art

Specific questions that are to be addressed include but are not limited to:

- What are the objectives of the proposed activity?
- Which process(es)/parameter(s) will be measured by the proposed activity to accomplish the objective(s)?
- What instrumentation will be used to measure process(es)/parameter(s)
- Which objective(s) of the safety case does the proposed activity support and why?

Backup Slides

Base Case Temperature Fields at Alcove Scale

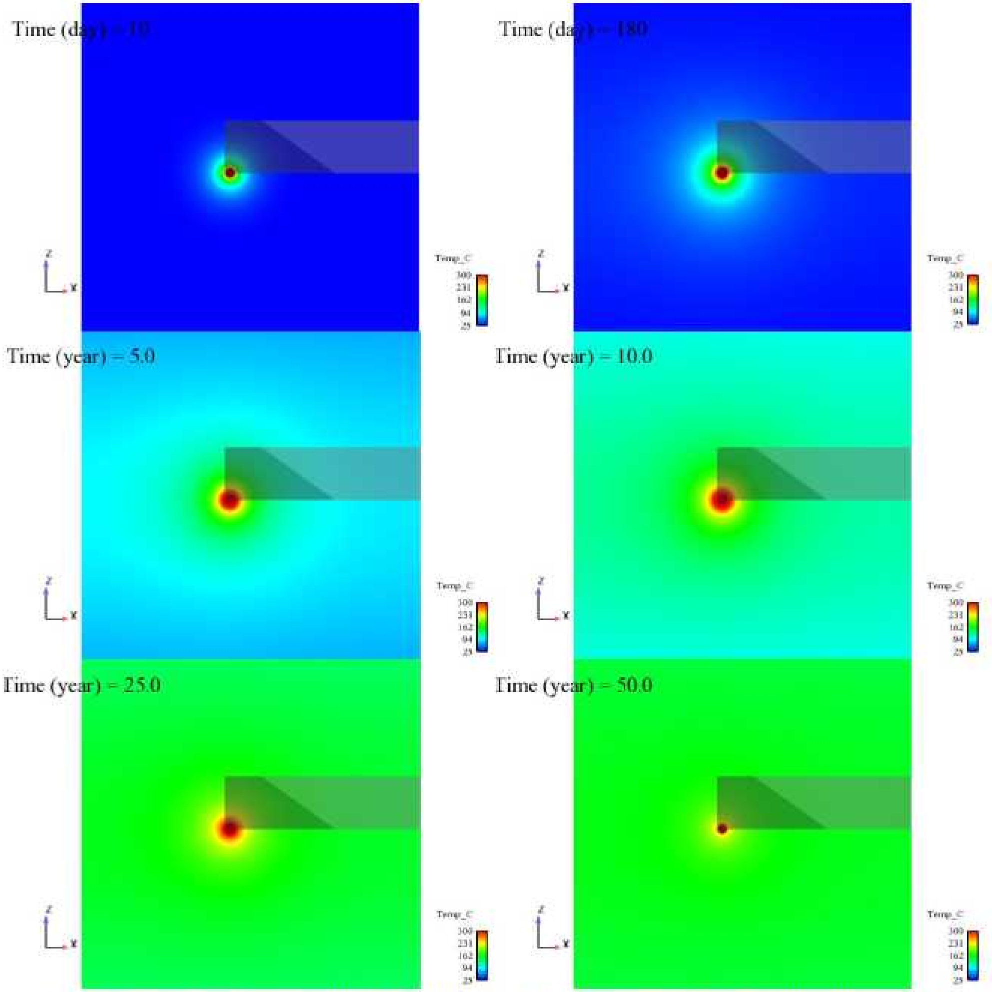


Figure 4.1. Base Case temperature (C) fields at the alcove-scale at six simulation times for a vertical plane through the center of the waste package, along the center of the alcove

Steady State

First, the characteristic time to steady state is on the order of 60 years. Figure 4 shows time evolution of temperature for two heat loads at both the center of the canisters and at the center of the pillar separating rooms. To ensure steady state results, we present all calculations at 200 years. Figure 5 shows a typical simulation result at steady state (200 yrs), for a case of 220 W/canister with 0.3 m (1 ft.) separation between canisters.

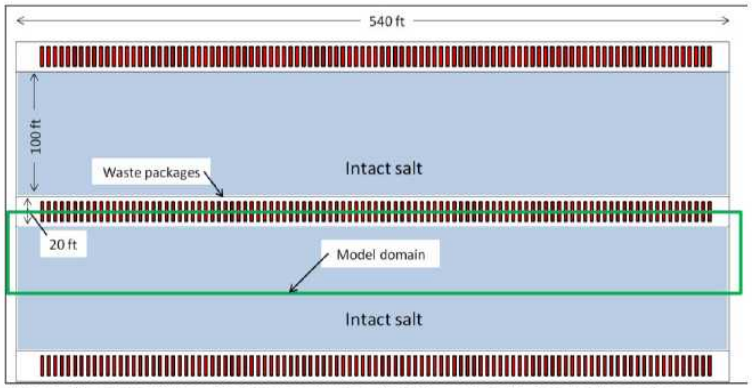


Figure 1. Plan view of the modeled waste canister configuration and model domain. Diagram is not

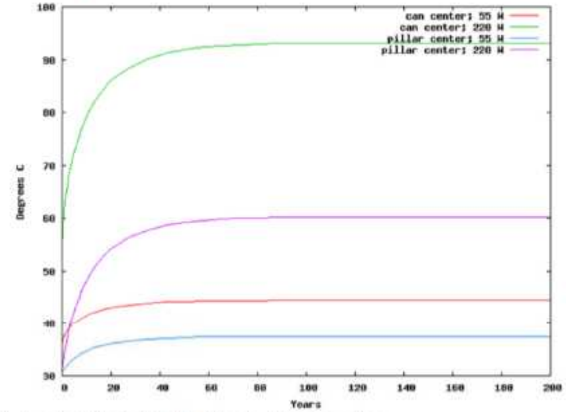


Figure 4. Time to steady state for two heat loads at two locations

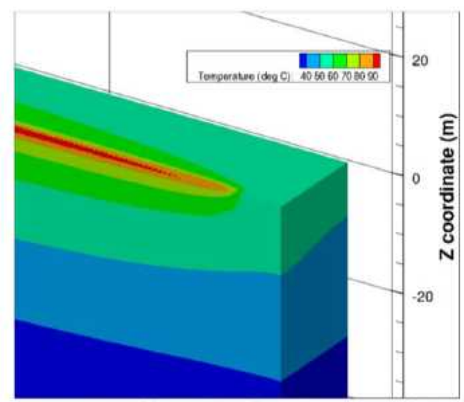
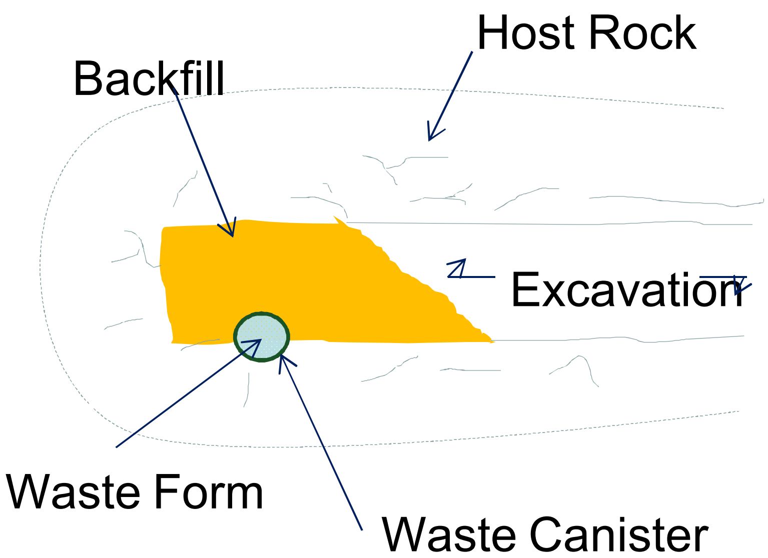


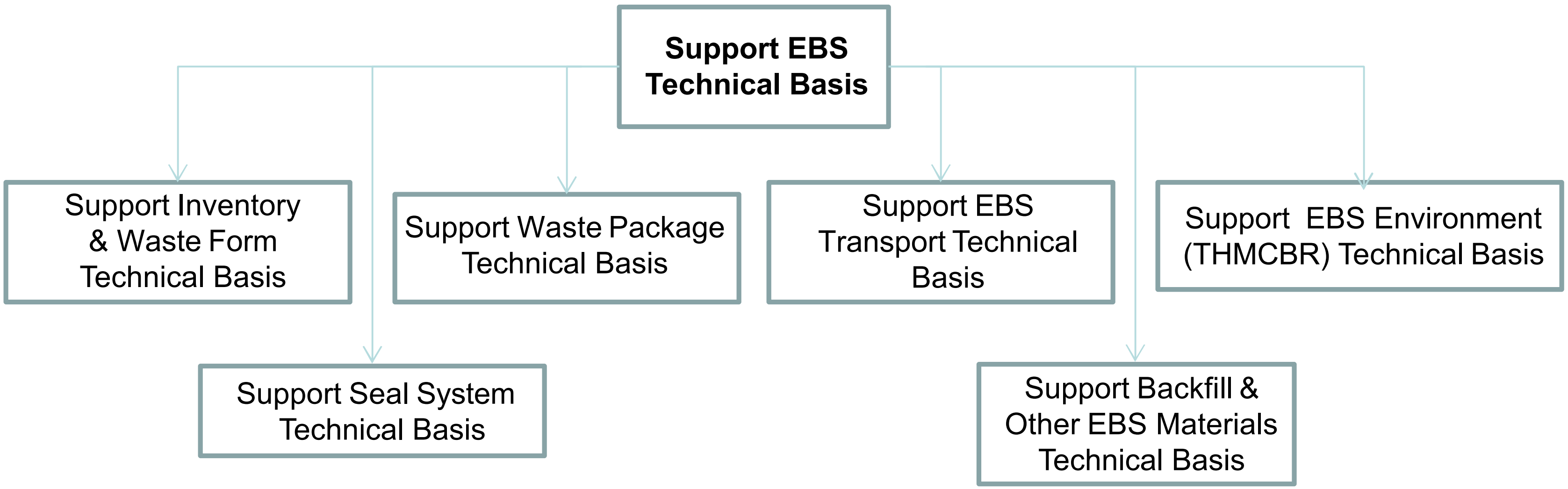
Figure 5. Temperature after 200 years with 220 W canisters. Upper part of model is cut out to view the

Host Rock and EBS Barrier Functions

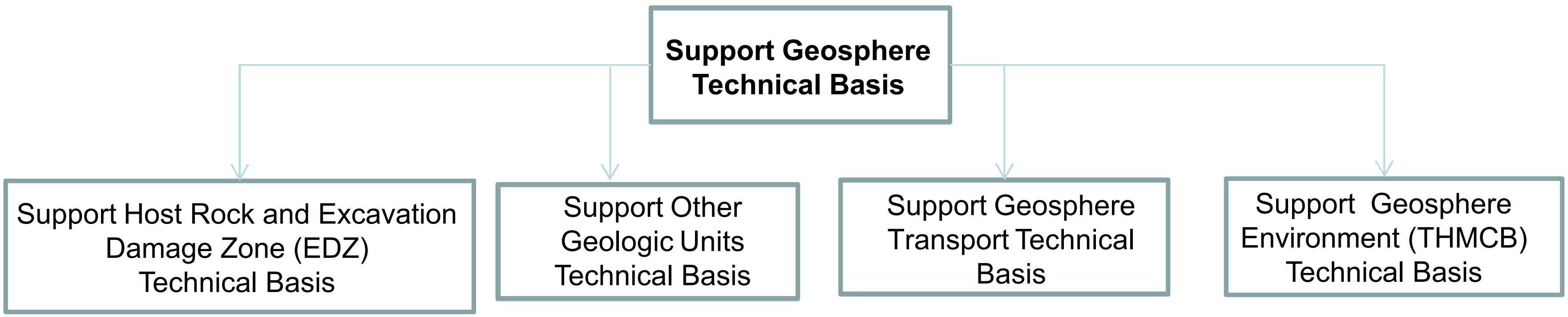


- Host rock (and EDZ) – limits the flow of brine into the waste emplacement drift, self heals, and limits the release rate of dissolved radionuclides to the geosphere
- Crushed Salt Backfill – conducts heat to the host rock, stabilizes and limits drift closure, limits the release rate of radionuclides, and provides a long-term barrier to inflowing brine
- Waste Canister – prevents water from contacting the waste and provides containment of the waste for an adequate period of time
- Waste Form – limits the release rate of radionuclides subsequent to container breach

EBS Technical Basis Objective



Geosphere Technical Basis Objective



Pre-Closure Safety Evaluation & Operations Objective