

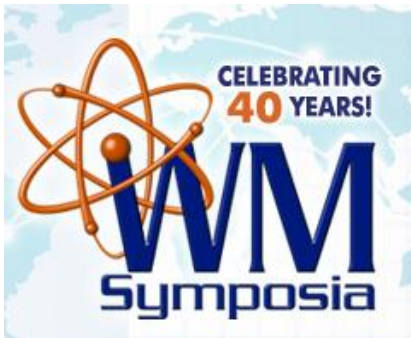
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# A Decision Methodology for Prioritizing R&D Supporting Geologic Disposal of SNF/HLW in Salt

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and Bob MacKinnon

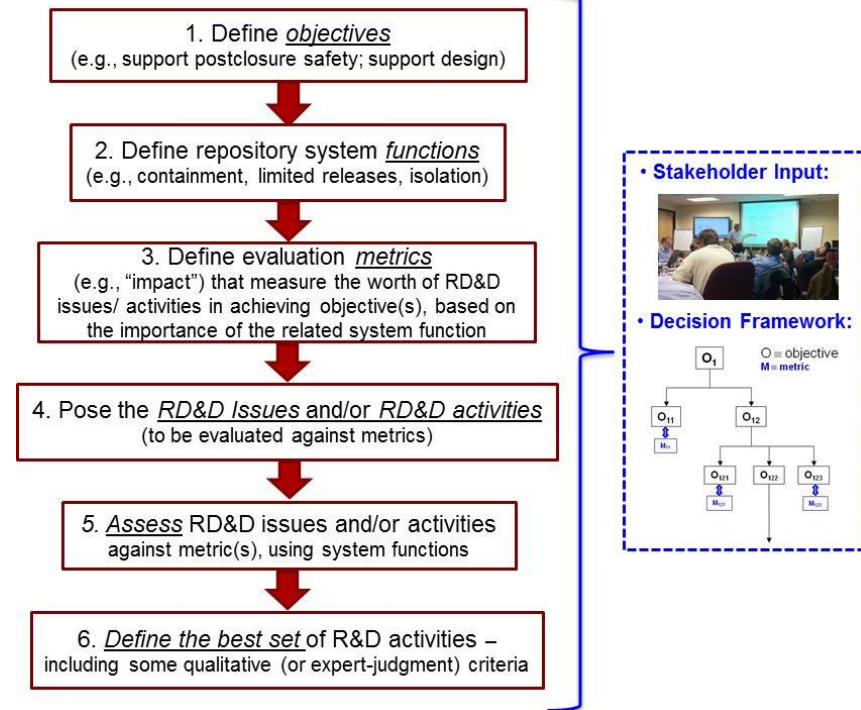
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# Synopsis

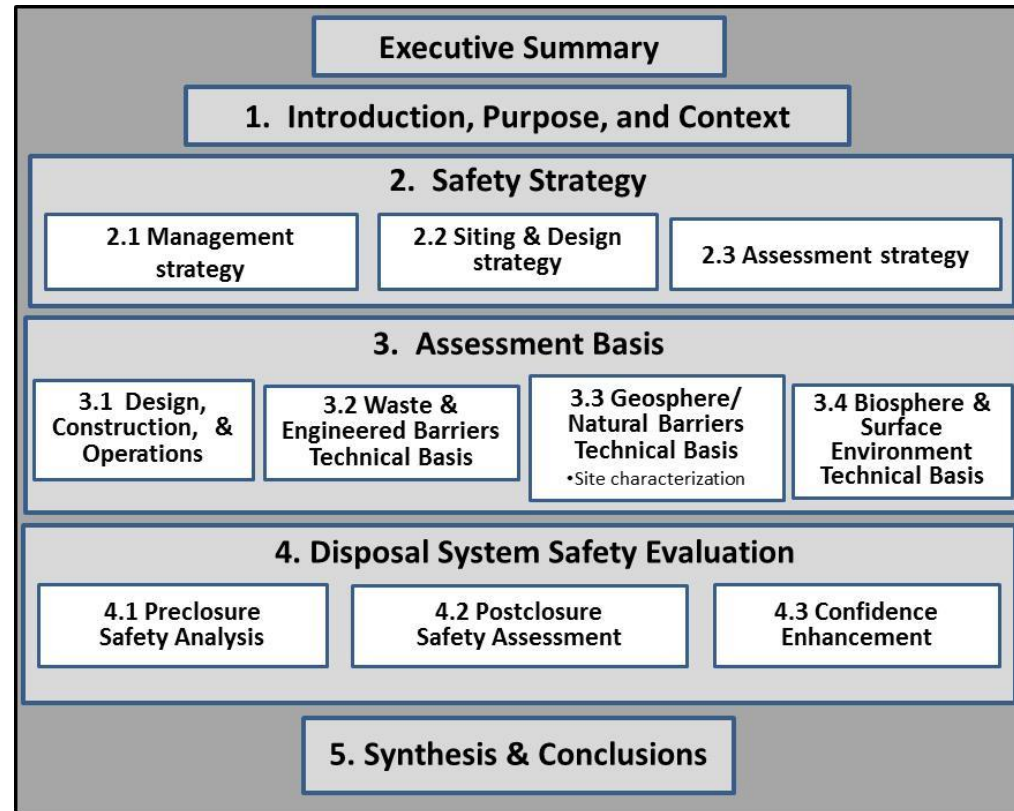
- **Problem:** Prioritize future RD&D activities that best support the development and assessment of generic mined HLW repositories in bedded salt
- **Method:** Use standard decision analysis methodology:
  - Define a suite of RD&D issues/needs and a corresponding set of RD&D activities to help resolve those issues
    - Use extensive current knowledge base for salt repository sciences
  - Define a set of objectives against which to measure the success of the RD&D activities
  - Define a metric for each objective to quantify the degree of success of each RD&D activity, according to the activity's importance to its related system functions
- **Safety case context:** use elements of the safety case as the objectives in the objectives hierarchy, i.e.,
  - How well does an RD&D activity support the eventual safety case?
- **Salt RD&D workshop:** held in March 2013 to review issues and methodology



# Safety Case – Definition & Roles

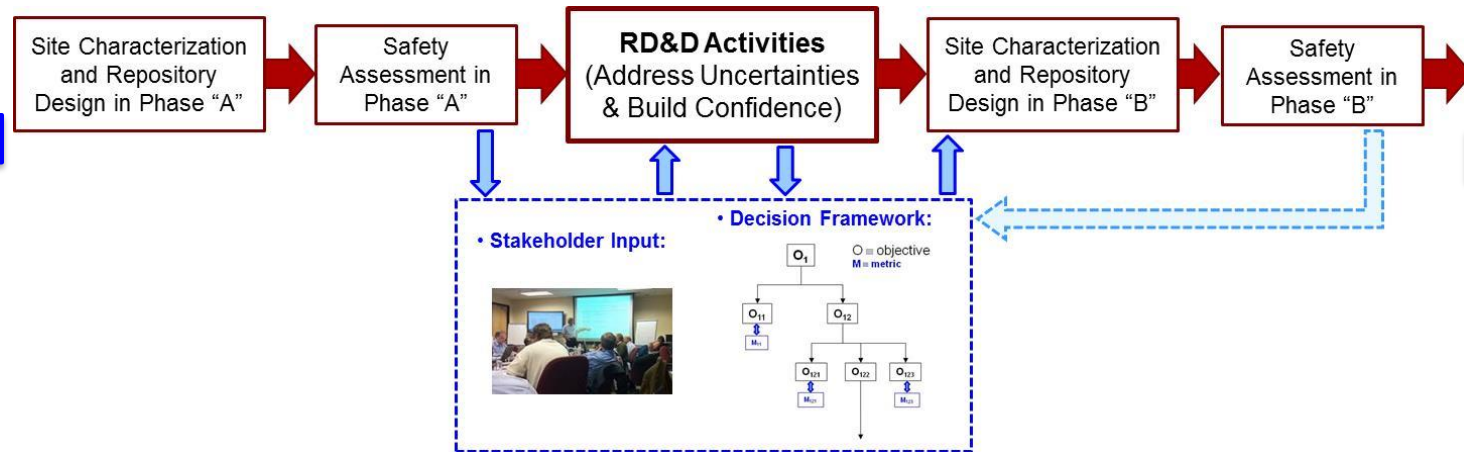
- “A safety case is a formal compilation of evidence, analyses and arguments that quantify and substantiate a claim that the repository will be safe.” (NEA 2013)
  - Quantitative information – calculated values for safety standards and indicators, including uncertainty (e.g., based on a quantitative safety or performance assessment)
  - Qualitative information – supporting evidence that builds confidence in the quality of the underlying science and conclusions (e.g, natural analogs)
- Two major roles:
  - Management: a tool to guide the activities of the implementer through the various phases of repository development
  - Communication: transparently explain the current understanding of safety to a broad range of stakeholders, decision makers, and the general public

## Structure and Elements of the Safety Case

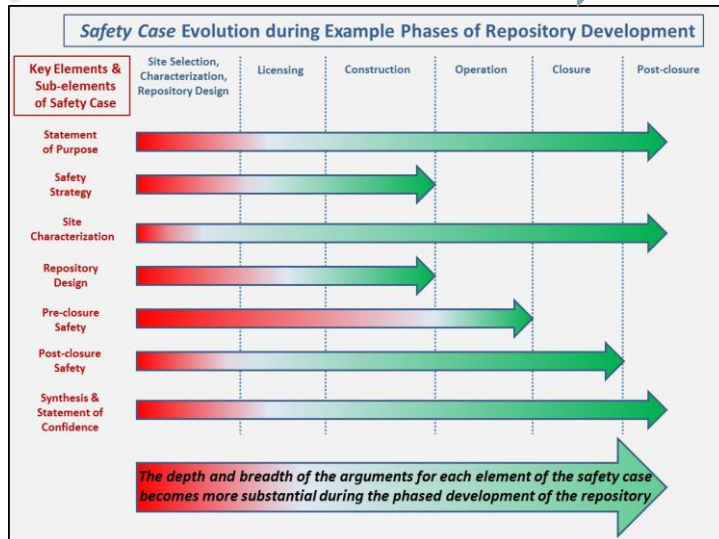


# Role of RD&D in Evolution of the Safety Case

- Iteration of Safety Assessment and Site Characterization/Design:



**Safety Case Evolution**

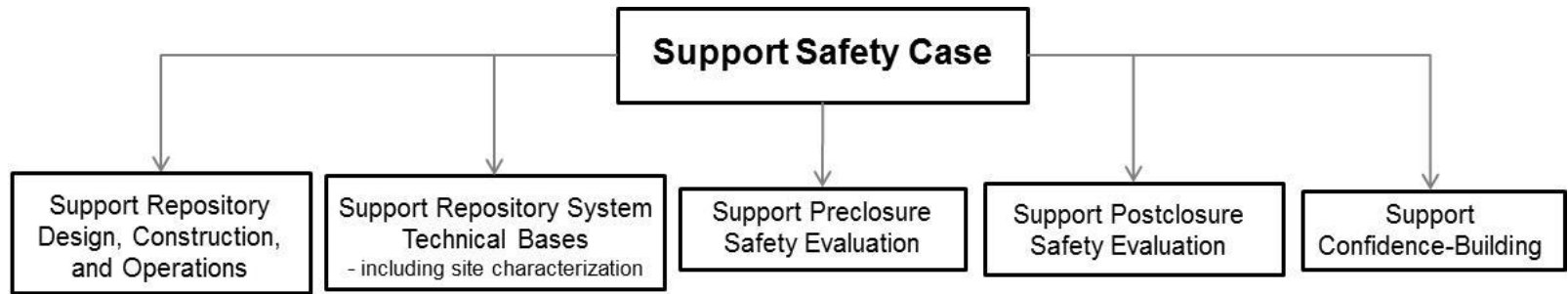


- Safety case provides a structured framework to assist in prioritizing the technical work in the next phase, to reduce uncertainties and enhance confidence
- Safety understanding and the associated technical bases evolve with phases of repository development, via RD&D

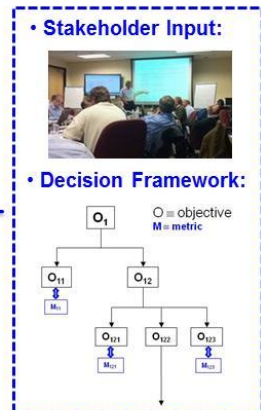
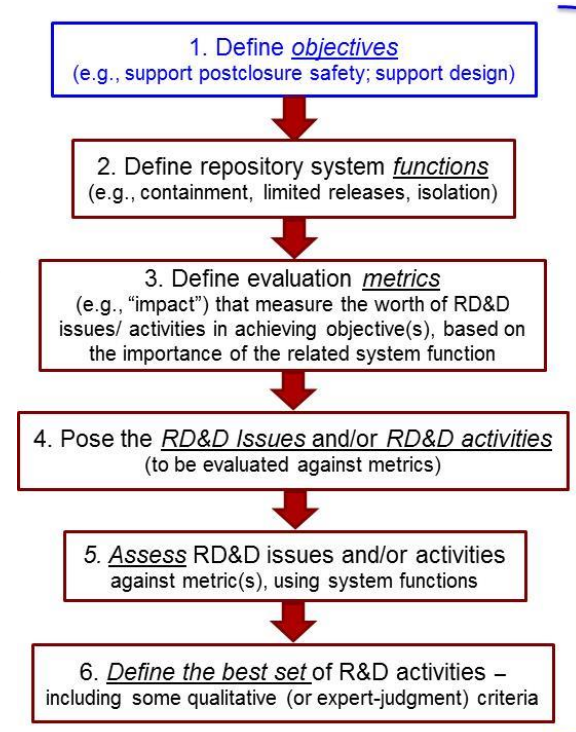
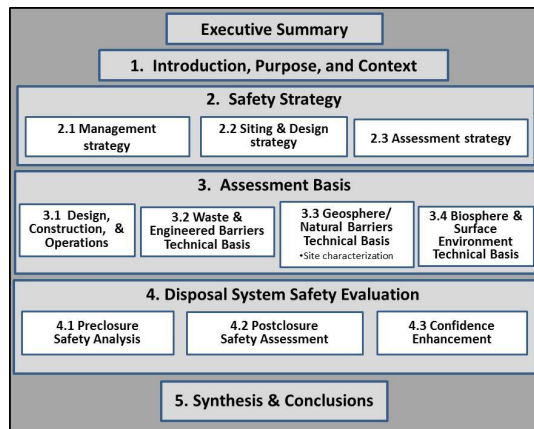
# Basis for Formulation of RD&D Issue List

- In a safety or licensing case, *all* RD&D issues and FEPs must ultimately be addressed with technical arguments and evidence:
  - But at this earlier stage of the safety case (still generic) and with the currently limited resources, prioritization of RD&D activities to address these issues is important
  - Existing broad technical basis for salt (WIPP, Germany) implies a reduced set of high importance issues, with most of those related to the effects of heat generation
- RD&D Issue categories (example individual issues shown on a later slide):
  - Feature/process issues
  - Modeling issues
  - *In-situ* testing/design/operations issues
  - Confidence-building Issues
- Sources for Salt RD&D Issues:
  - DOE UFD R&D Roadmap and FEPs list; Hansen and Leigh 2011; F. Hansen 2013 IHLRWMC paper; Gorleben FEPs list; expert judgment

# Objectives Hierarchy to Evaluate Issues/Activities

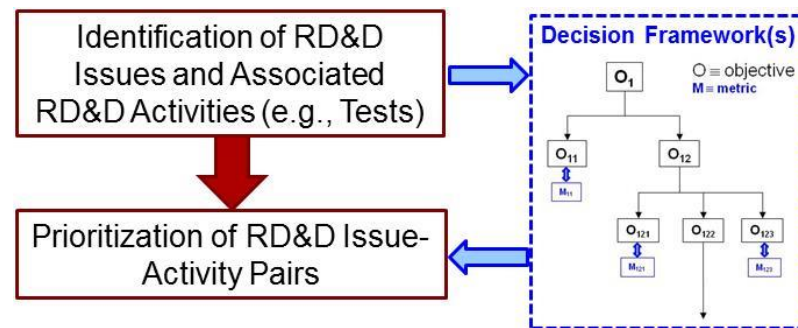


- Use key elements of the safety case as high-level objectives, e.g., repository design, preclosure safety, postclosure safety, and confidence-building
  - How well does an RD&D activity support the eventual safety case?



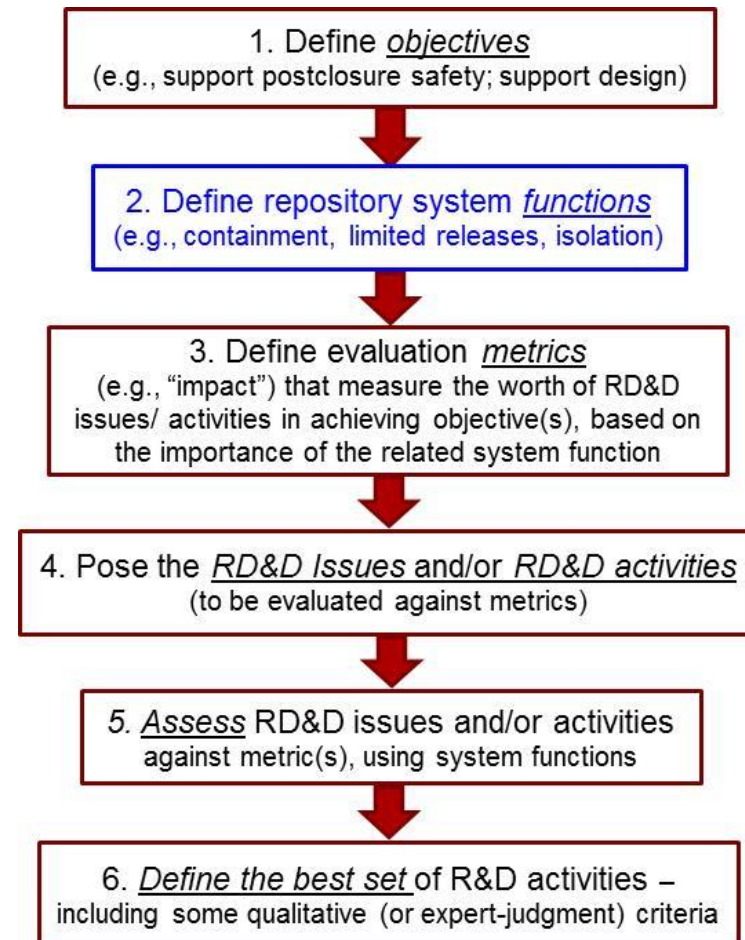
# Some Assumptions

- 1) At this stage of generic repository RD&D, we rely primarily on the objective “Support Postclosure Safety Evaluation”
  - Design a metric “Importance to Postclosure Safety” that measures how well an RD&D activity supports the postclosure safety evaluation
  - Define “system functions” for postclosure safety, i.e., what must the system do successfully to achieve postclosure safety; use these to formulate the metric
  - The metric should determine or measure the importance of any RD&D activity according to its ability to increasing our confidence in the successful operation of postclosure *safety functions* (defined on next slide)
  
- 2) Prioritize each proposed RD&D *activity* by evaluating the corresponding RD&D *issue* that the activity is designed to address:
  - The metric that measures the importance of the RD&D issue relative to postclosure safety is a “proxy” metric for measuring the importance of the corresponding RD&D activity



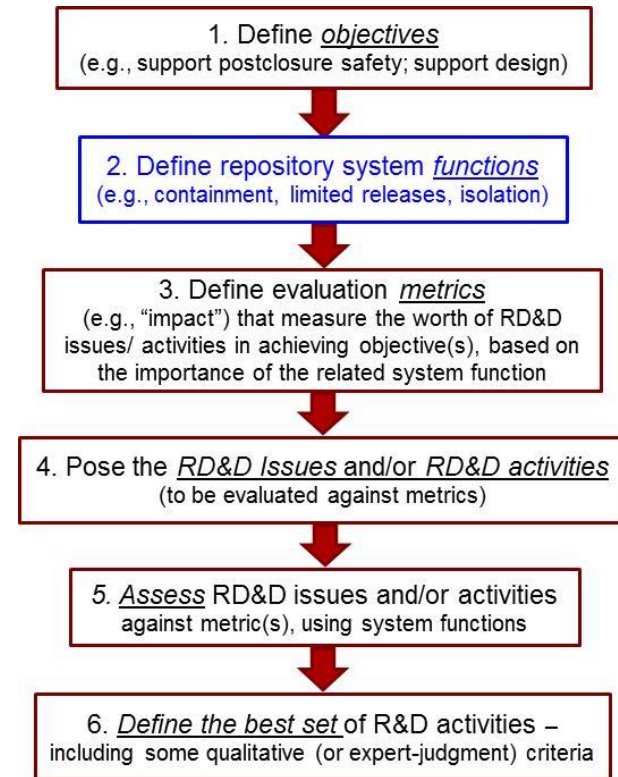
# Define System Safety Functions

- Postclosure safety functions identify key attributes of material barriers that are relied upon to prevent or limit contact of the emplaced waste with the biosphere
  - These material or physical barriers fall into two major categories: natural (e.g., the host rock formation) and engineered (i.e., the waste container and other man-made barriers).
  - Robust performance of physical barriers is facilitated when they work together, each complementing the other, which is the “multi-barrier” concept identified in various regulations
- Substantiation of the successful operation of the safety functions is provided by a quantitative postclosure safety assessment calculation
- Confidence in the long-term operation of *safety functions* is part of a successful safety strategy



# Define System Safety Functions\* (cont.)

- **Isolation/Stability Safety Function**— Aspects of the repository and geologic environment that isolate the waste from external events or changes, and therefore help maintain the integrity and longevity of the barriers
- **Containment**—Aspects of the repository that prevent fluid contact with the waste:
  - If groundwater does not contact the waste there is, in general, no release mechanism to transport radionuclides
  - {Note: An alternative definition of containment is provided at 10 CFR 60.2: “Containment means the confinement of radioactive waste within a designated boundary.”}
- **Limited or Delayed Releases**— Aspects of the repository that delay or reduce the transfer of radionuclides to the accessible environment after the *containment* function is compromised



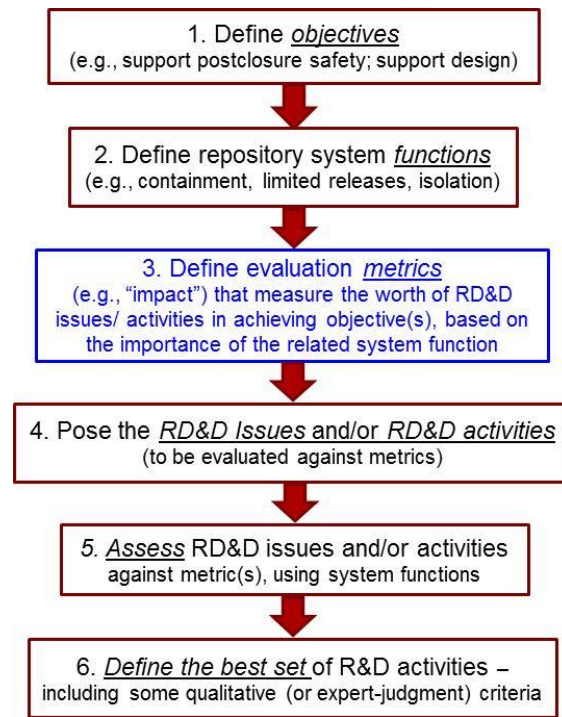
\*These definitions are from Bailey, L., et al. 2011. *PAMINA (Performance Assessment Methodologies in Application to Guide the Development of the Safety Case): European Handbook of the state-of-the-art of safety assessments of geological repositories—Part 1*. European Commission. January 31, 2011. <http://www.ip-pamina.eu/>

# Define Metric(s)

- Define “*Importance to Postclosure Safety*” metric based on system safety functions:

$$\boxed{\text{Importance of RD\&D Issue}} = \boxed{\text{Impact of RD\&D Issue on a Safety Function}} + \boxed{\text{Function Level of the Safety Function}}$$

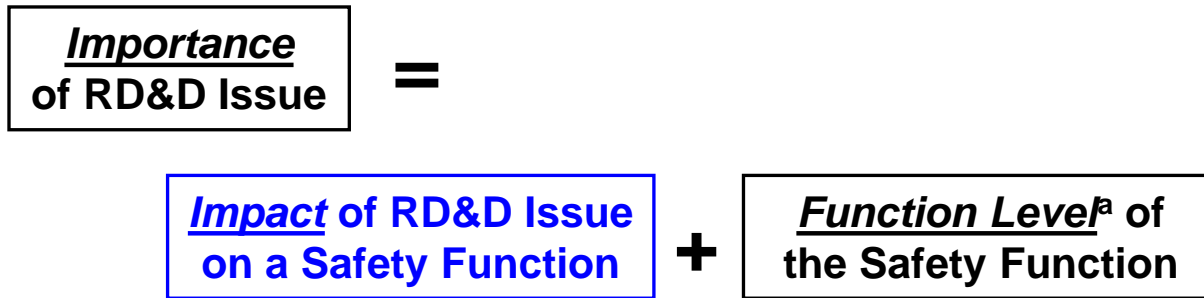
- “**Function level**” for any safety function is defined as either *primary* or *secondary*:
  - A *primary* safety function operates from the time of closure to prevent transfer of radionuclides to the biosphere
  - A *secondary* safety function is only operative if a primary function fails, for whatever reason



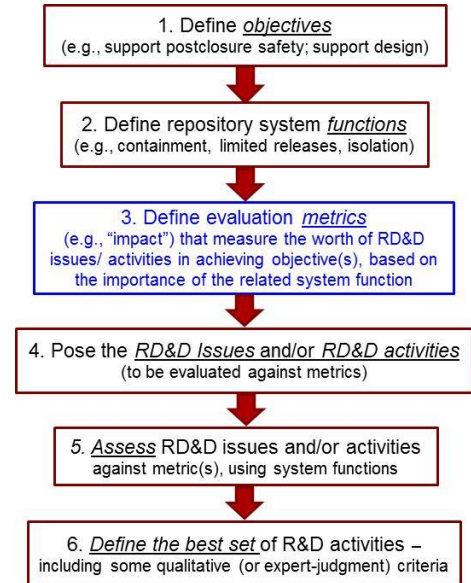
Function	Type	Function Level	Definition	Examples of Key Associated Parameter(s) or Characteristic(s)
<b>Isolation/stability</b>	Safety	Primary (P)	Aspects of the repository and geologic environment that isolate the waste from external events or changes, and therefore help maintain the integrity and longevity of the barriers.	<ul style="list-style-type: none"> <li>(high) seal integrity</li> <li>(thick) host rock zone</li> <li>(non-) communication between salt beds and interbeds</li> </ul>
<b>Containment</b>	Safety	Primary (P)	Aspects of the repository that prevent fluid contact with the waste.	<ul style="list-style-type: none"> <li>(very low or zero) permeability</li> </ul>
<b>Limited or delayed releases</b>	Safety	Secondary (S)	Aspects of the repository that delay or reduce the transfer of radionuclides to the accessible environment after the containment function is compromised.	<ul style="list-style-type: none"> <li>(high) sorption</li> <li>(low) solubility</li> <li>(low) dissolution rates</li> </ul>
<b>Retrievability</b>	Design	Primary (P)	Aspects of the repository that allow for retrievability of the emplaced waste without any releases, for a specified period of time after closure.	<ul style="list-style-type: none"> <li>(sufficient) WP thickness</li> </ul>

“Design” function →

# Define Metric(s) – (cont.)



<sup>a</sup> Also called the “significance level”



- “Impact” of an RD&D Issue on performance of a safety/design function (for process/parameter issues), or on confidence in the demonstration of that performance (for modeling or *in situ* testing issues):

Impact of an RD&D Issue	
<b>D</b>	Direct and potentially significant impact on the success of a safety or design function
<b>I</b>	Indirect but potentially significant impact on the success of a safety or design function
<b>W</b>	Weak impact (whether direct or indirect) on the success of a safety or design function

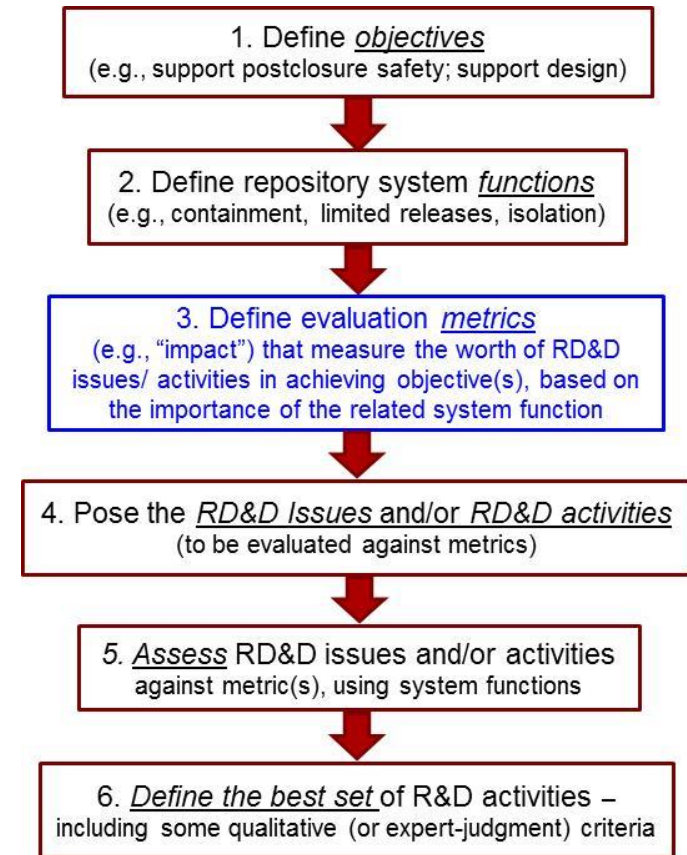
# Define Metric(s) – (cont.)

$$\boxed{\text{Importance of RD\&D Issue}} = \boxed{\text{Impact of RD\&D Issue on a Safety Function}} + \boxed{\text{Function Level of the Safety Function}}$$

- “**Importance**” value ratings (H, M, or L) for RD&D issues (based on impact and function level):

Importance Value Rating	= Impact Level	+ Function Level
High: H=(D,P)	Direct (D)	Primary (P)
Medium: M=(I,P)	Indirect (I)	Primary (P)
Low: L=(W,P)	Weak (W)	Primary (P)
Low: L=(D,S)	Direct (D)	Secondary (S)
Low: L=(I,S)	Indirect (I)	Secondary (S)
Low: L=(W,S)	Weak (W)	Secondary (S)

(Note: An R&D Issue receives a rating according to its highest function-impact combination, i.e., it may receive an L rating for one function/impact but if it gets an H for another function/impact, it inherits that highest rating.)

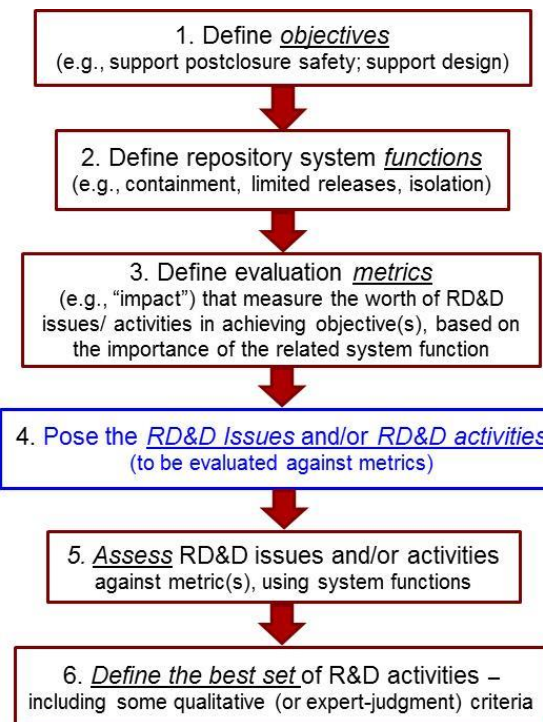
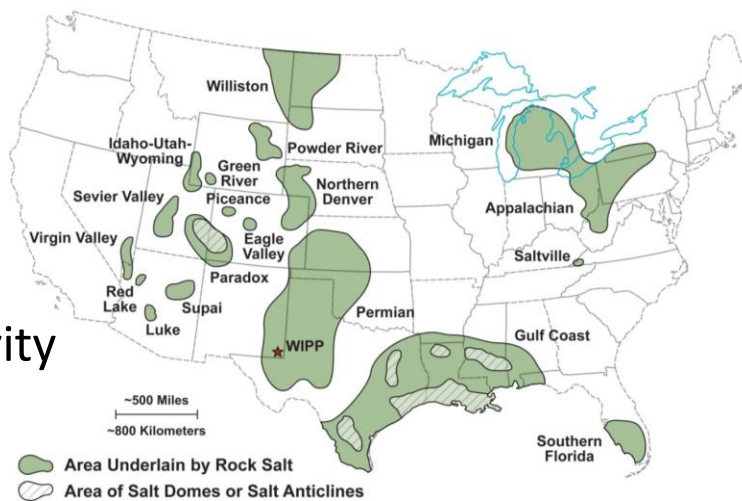


# Pose the Salt RD&D Issues

- Set of remaining salt RD&D issues is based on the existing technical knowledge base — derived from lab, field, and *in situ* testing, as well as prior performance assessment modeling and process modeling

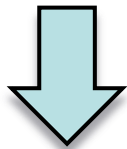
## Salt Attributes and Distribution

- 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 over a wide geographic distribution in the U.S.

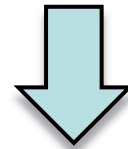


# Near Field Salt Evolution → Barrier Functions

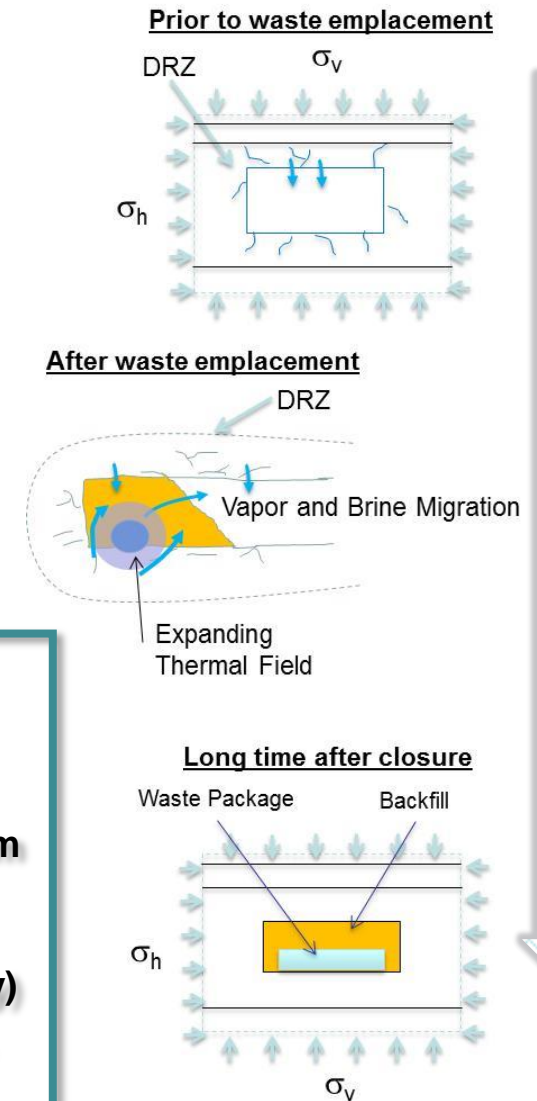
- Excavations will creep towards closure and potential flow paths for brine/gas will be sealed by *in situ* stresses
- Creep closure is accelerated under higher temperatures
- Crushed salt backfill stabilizes converging host rock and limits excavation volume reduction and fracturing
- *In situ* rock stress consolidates backfill into a mass comparable to intact salt with low permeability



**Barrier Functions = Safety Functions  
applied to Individual Features/Barriers:**

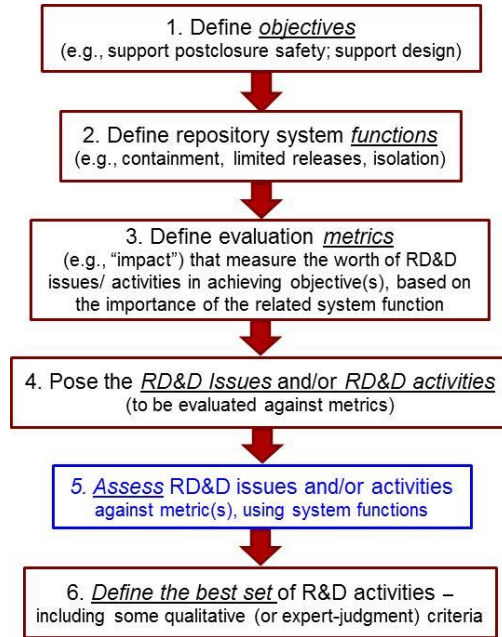


- **Host rock (and EDZ)** – strongly limits or prevents the flow of brine into the waste emplacement drift, self heals, and greatly limits or prevents the release of dissolved radionuclides to the geosphere
- **Crushed Salt Backfill** – strongly limits or prevents the release of radionuclides, stabilizes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



# Example Salt RD&D Feature/Process Issues

- 48 salt RD&D technical issues were given “pre-workshop” importance ratings for the nominal scenario and high heat load
- 30 feature/process (“FEPs”) issues; 8 modeling issues; 4 *in situ* testing issues; 6 confidence-building issues – see conference paper for complete list

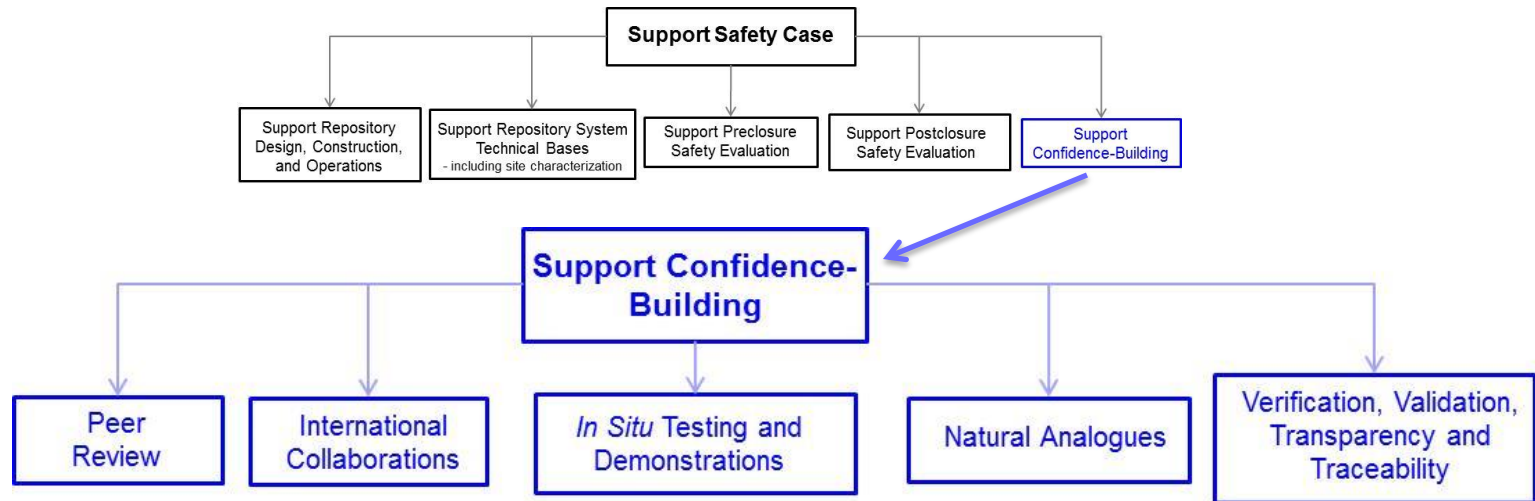


Salt RD&D Technical Issue	Issue Importance Rating	Explanation of Issue Importance Rating
<b>Wastes and Engineered Features (EBS) Feature/Process Issues</b>		
1. Inventory and WP Loading	M (= I,P)	Indirectly related to limited and delayed releases through elemental composition of inventory (L = I,S), but also indirectly related to containment (permeability) through heat loading density and associated affects (M = I,P)
2. Physical-chemical properties of crushed salt backfill at emplacement	M (= I,P)	Indirectly related to the final state of the backfill permeability (containment function of the backfill)
3. Changes in physical-chemical properties of crushed salt backfill after waste emplacement	H (= D,P)	Directly related to maintaining the containment function of the backfill by directly changing its permeability
4. Changes in chemical characteristics of brine in the backfill and EBS	M (= I,P)	Indirectly related to backfill permeability through WP corrosion and subsequent gas generation (M) Indirectly related to limited and delayed releases (L)
5. Mechanical response of backfill	H (= D,P)	Directly related to host rock permeability in the EDZ and to backfill permeability (i.e., to containment)
6. Impact of mechanical loading on performance of the WP	H (= D,P)	Directly related to retrievability
7. Brine and vapor movement in the backfill and emplacement drift, including evaporation and condensation	H (= D, P)	Brine and vapor movement in the EBS are directly related to containment by definition (fluid contact with waste), although this movement is much less likely after the backfill consolidates and the thermal period ends. Also, can indirectly result in changes to backfill permeability (containment)—through gas generation from WP corrosion or through trapping of water during consolidation

Importance Value Rating	= Impact Level	+ Function Level
High: H=(D,P)	Direct (D)	Primary (P)
Medium: M=(I,P)	Indirect (I)	Primary (P)
Low: L=(W,P)	Weak (W)	Primary (P)
Low: L=(D,S)	Direct (D)	Secondary (S)
Low: L=(I,S)	Indirect (I)	Secondary (S)
Low: L=(W,S)	Weak (W)	Secondary (S)

# Use of the Confidence-Building Objective

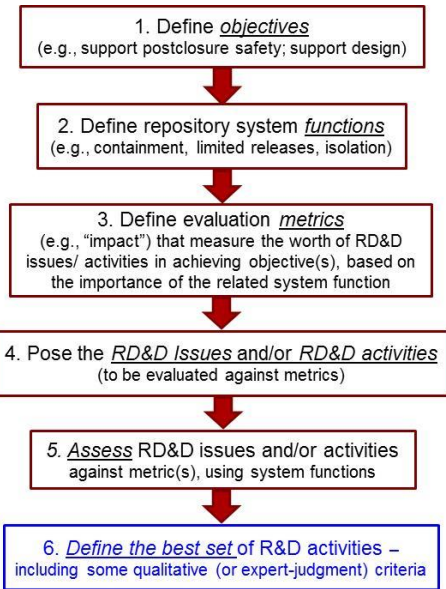
- *Confidence-building* is the another important safety-case objective to be considered in designing test/modeling activities to resolve RD&D issues:



- Decision-makers will decide what weight or importance to give to the confidence-building objective versus the postclosure safety objective:
  - Given a more mature technical basis, confidence-building activities (such as large-scale *in situ* demonstration tests) may receive a higher importance rating than FEPs-specific RD&D activities (e.g., constitutive model development)
  - Can be used to refine/revise the postclosure safety importance ratings — e.g., to move an “M” issue to an “H” level, based on current “*state-of-the-art*” knowledge:
    - Confidence-building activities (or any RD&D activities) are more justified for an “M” safety issue with high parameter/model uncertainty than for an “H” issue with low uncertainty

# Salt RD&D Workshop

- Joint DOE-NE/DOE-EM workshop, March 2013, in Albuquerque, NM: “Advancing the Science and Engineering Supporting Deep Geologic Disposal of Nuclear Waste in Salt”
- Overall goal: Identify RD&D activities that have the greatest potential to contribute to the advancement of deep geologic disposal of heat-generating HLW in bedded salt—generally only defined for “H” issues at this time
- Major tasks:
  - Review pre-workshop RD&D issue list and the associated importance ratings—provide comments/revisions as necessary
    - M and L issues may be moved to H if warranted; give reasons
  - For high importance (“H”) items that are not currently being addressed by UFD RD&D tasks (see issue table), define specific activities needed to advance the state of the art
  - Answer the test questionnaire for each newly proposed activity
- Day 1: two breakout groups in the afternoon:
  - Group 1: Review postclosure FEPs issues and modeling issues
  - Group 2: Review preclosure design and *in situ* testing issues
- Day 2: the combined group discussed *in situ* field testing



# Summary

- Standard decision analysis methodology adapted to rank the importance of RD&D issues and associated RD&D activities needed to support disposal of heat-generating HLW in bedded salt
- RD&D issues/activities based on current extensive salt knowledge base
- Decision analysis “objectives hierarchy” based on elements of the generic safety case
- Postclosure safety functions (e.g., containment) used to formulate an “Importance to Postclosure Safety” metric for ranking RD&D issues — the sole quantitative metric used at this generic stage of repository research
- “Confidence-building” objective used to modify postclosure safety issue rankings where appropriate
- Salt RD&D workshop reviewed the methodology, rankings, and issues, as well as the importance of large-scale *in situ* testing in salt
  - Workshop participants moved some issues to an “H” ranking based on their importance to the human intrusion scenario

# Backup Slides

# Test Questionnaire

- 1) Name of test:
- 2) Test objectives, description, and type (lab, field, etc.):
- 3) RD&D issue(s) addressed by test (field tests should include one or more “H”-rated issues):
- 4) Safety case objectives addressed by test (e.g., postclosure safety; preclosure safety; confidence building) and why the test is important to the safety case:
  - List objectives in order of applicability (e.g., 1. Postclosure safety, 2. Confidence-building, etc.)
- 5) For the proposed test describe the current “state of the art” knowledge regarding the issue(s) it addresses; in other words, why is this data necessary?
- 6) Define the data that will be collected/measured (e.g., name and description of process(es)/parameter(s), time duration, spatial scale, frequency, accuracy):
  - Describe how the data will be collected
- 7) Define the instrumentation that will be used to measure process(es)/parameter(s) and define the instrumentation placement or layout:

# Test Questionnaire (cont.)

- 8) Define the pre-and post-test modeling/simulation needs for the activity, including:
  - Description and type of model addressed by test (constitutive; process; coupled process; N/A if testing for constructability)
- 9) List system features involved in test (e.g., waste package; backfill; seal system; DRZ; pristine host rock; etc.):
- 10) Time period of applicability for data gathered: pre-emplacement; preclosure, postclosure:
  - E.g., data gathered applies to processes occurring during first 300 years after closure; data gathered applies to processes that occur over 10,000 years after closure; etc.
- 11) For field tests define additional lab tests or other separate activities/data needed to support this test: