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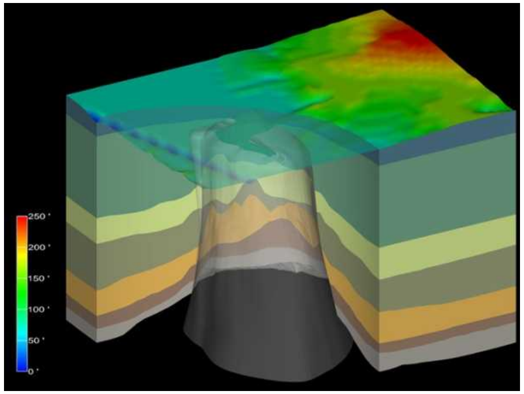

Safety Case – Iterations from Generic Studies to License Application

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12 – 16 September 2016

JRC Ispra (Italy)

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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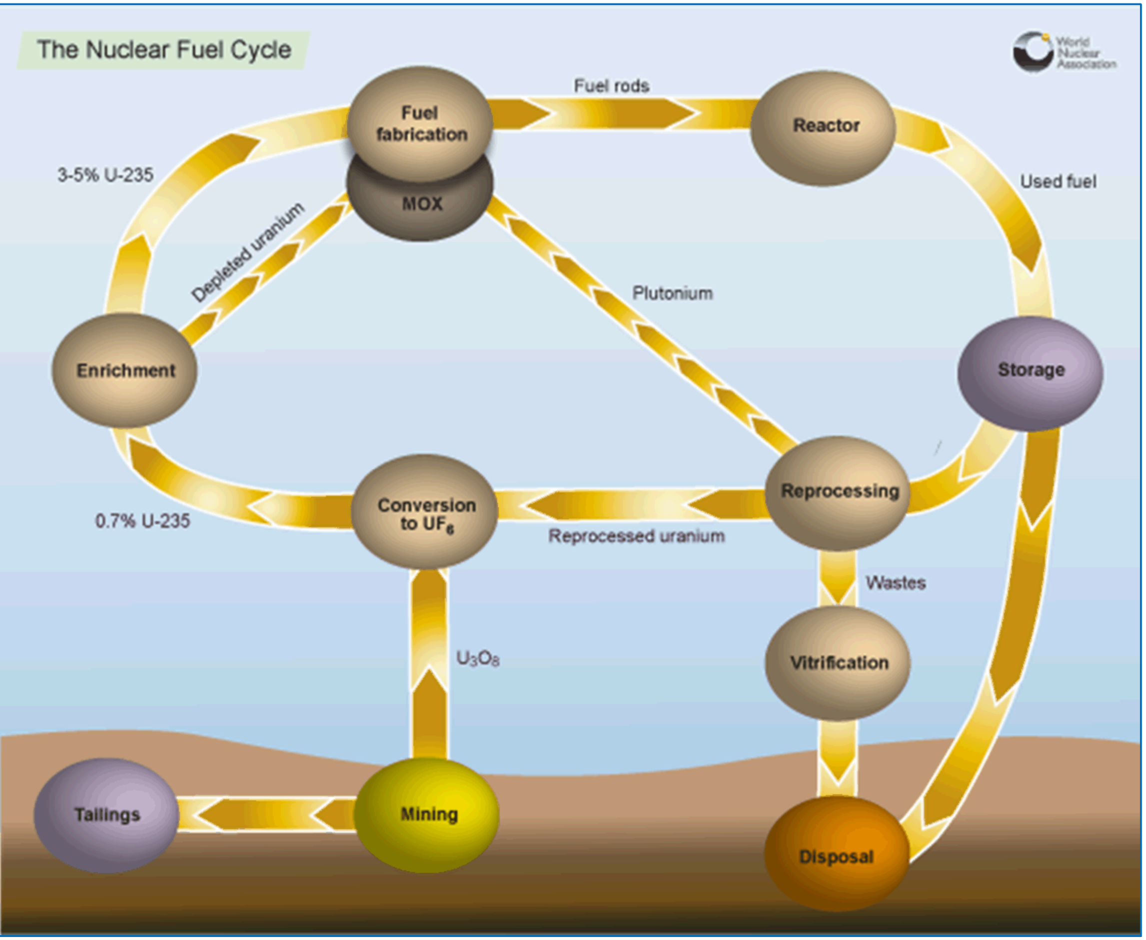
Nuclear Fuel Cycle



- **The Safety Case for Geological disposal demonstrates safety for:**
  - Transportation of the waste
  - Packaging of the waste
  - Construction of the repository
  - Operation of the repository
  - *Long-term period after closure of the repository*

Safe = risk to humans and the environment are acceptably low and meet regulatory requirements

Safety Case and Safety Assessment

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License Application (LA) for Construction Authorization

License Application for Construction Authorization – Documentation that demonstrates the repository implementer satisfies all regulatory and technical requirements applicable to the repository and constitutes an adequate basis for the regulator to exercise its statutory licensing authority. The LA is supported by a comprehensive Safety Case.

Safety Case (*Definition from Outcomes of the NEA MeSA Initiative, OECD 2012*)

"A safety case is the synthesis of evidence, analyses and arguments that quantify and substantiate a claim that the repository will be safe after closure and beyond the time when active control of the facility can be relied on."

Post-Closure Safety Assessment (or Performance Assessment)

A quantitative assessment of repository performance that predicts the long-term behavior of a repository, including the ability of the repository barriers to perform their safety functions, and plays a key role in substantiating that a repository will be safe and comply with regulatory safety requirements.

Geologic Repository License Application and Safety Case Development

- **International experience *should* lessen the technical challenges**

- NEA (2004). Post-closure safety cases for geological repositories. Nature and purpose. *OECD/NEA report 3679.* Paris.
- **Yucca Mountain Repository License Application: Safety Analysis Report, 2008**
- http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app/yucca-lic-app-safety-report.html
- NEA (2009a). Considering timescales in the post-closure safety of geological disposal of radioactive waste. *OECD/NEA report 6424*. Paris.
- NEA (2009b). International experiences in safety cases for geological repositories (INTESC). Outcomes of the INTESC project. *OECD/NEA report 6251*. Paris.
- IAEA (2011). Disposal of radioactive waste*. Specific Safety Requirements SSR-5.* IAEA, Vienna.
- THE POST-CLOSURE RADIOLOGICAL SAFETY CASE FOR A SPENT FUEL REPOSITORY IN SWEDEN An international peer review of the SKB license - application study of March 2011 (Final report)
- Posiva (2012c). Safety case for the disposal of spent nuclear fuel at Olkiluoto—synthesis, 2012. *POSIVA report 2012-12.* Posiva Oy, Eurajoki.
- The Safety Case for Deep Geological Disposal of Radioactive Waste: 2013 State of the Art Symposium Proceedings, 7-9 October 2013, Paris, France
- Posiva (2013a). Safety case for the disposal of spent nuclear fuel at Olkiluoto—performance assessment 2012. *POSIVA report 2012-04.* Posiva Oy, Eurajoki.
- Posiva (2013b). Safety case for the disposal of spent nuclear fuel at Olkiluoto—assessment of radionuclide release scenarios for the repository system 2012. *POSIVA report 2012-09.* Posiva Oy, Eurajoki.

What is a deep geologic repository?

An engineered facility for safe handling and disposal of nuclear waste that includes disposal rooms or tunnels excavated sufficiently deep beneath the surface to ensure isolation of the waste from external changes or events. The underground facility typically comprises engineered and geologic barriers that act together to contain the waste within the facility and to limit and delay the release of radionuclides to the surrounding geosphere subsequent to loss of containment. Typical engineered barrier systems include the following components - ***waste form (and inventory), waste package, buffer/backfill, and engineered seals.***

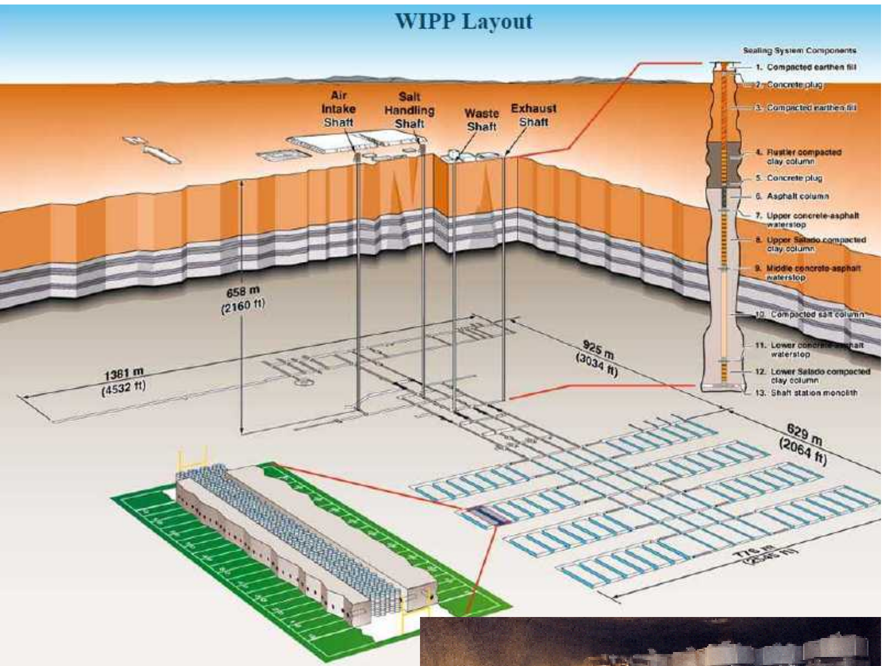
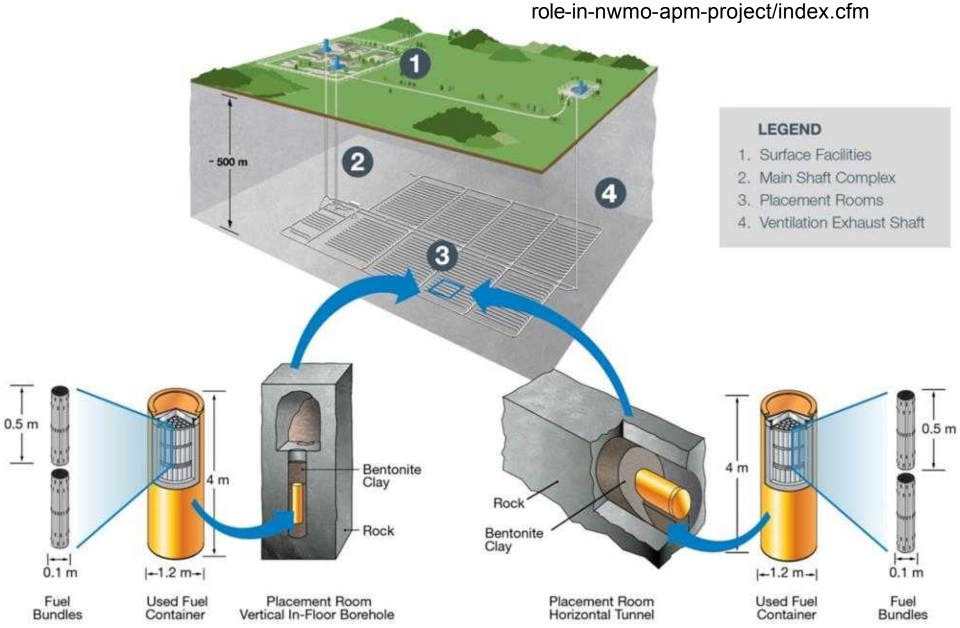
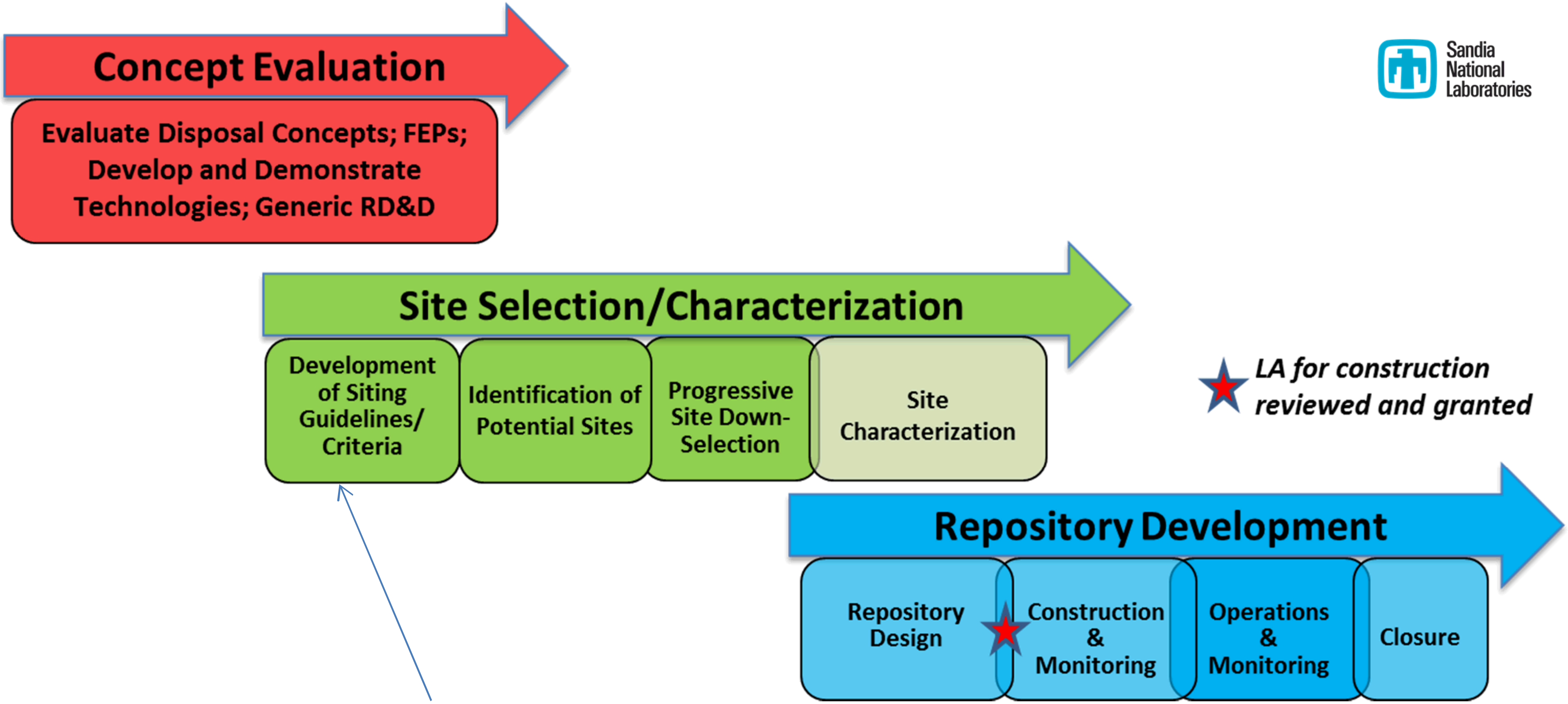
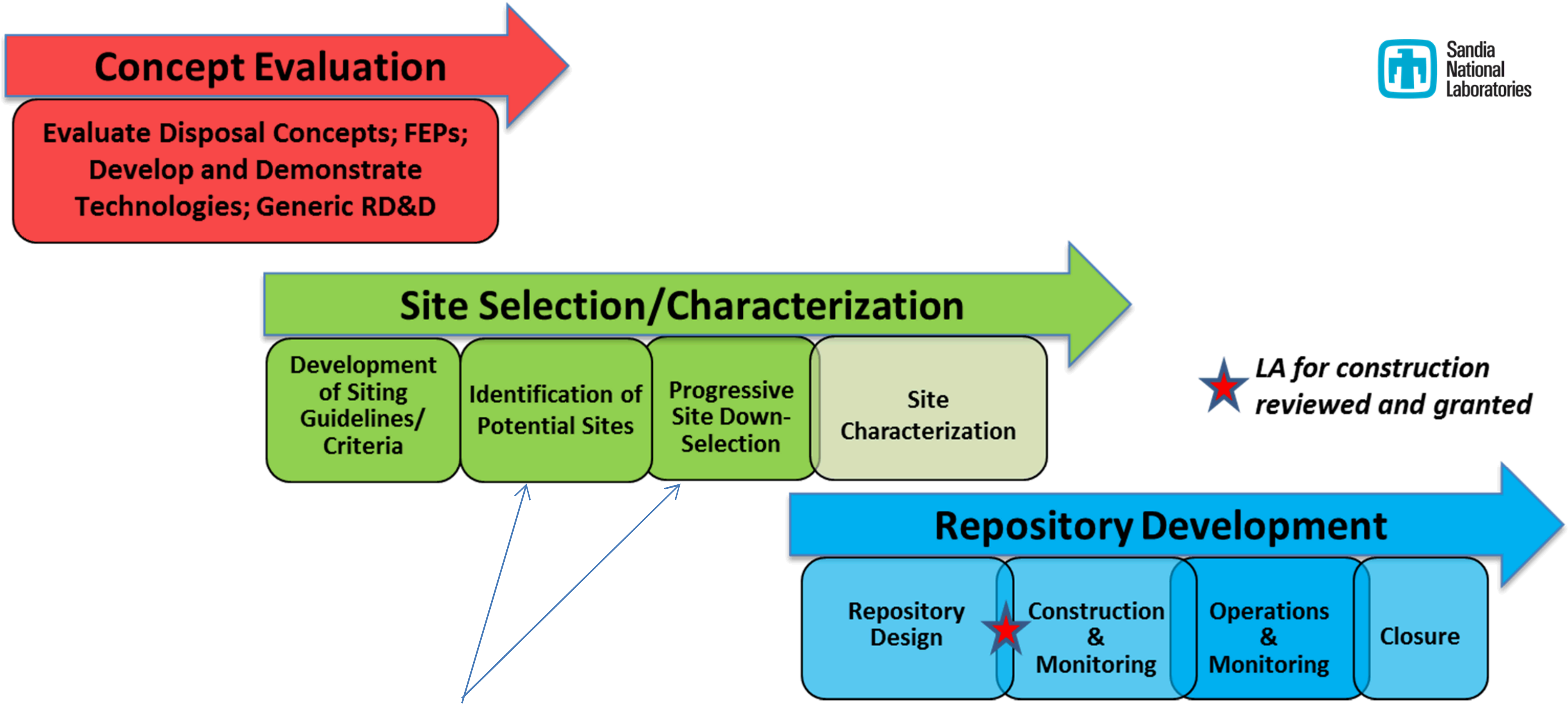


Figure Source: https://www.cnsc-ccsn.gc.ca/eng/waste/high-level-waste/cnsc-role-in-nwmo-apm-project/index.cfm

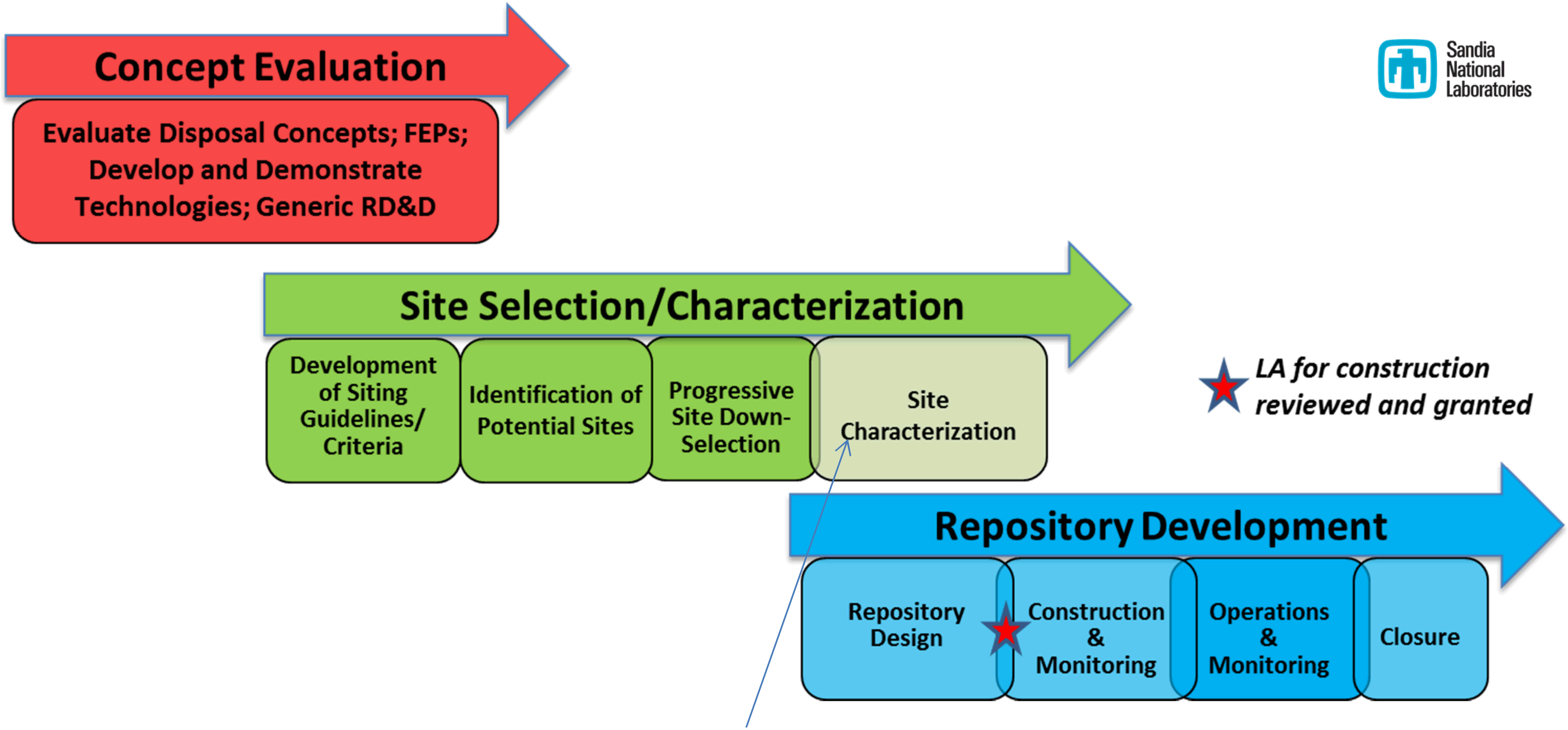




- Exclude sites that have appreciable natural resources, are located on protected lands, or have cultural or ecological value
- Provide reasonable expectation that the candidate site has geologic characteristics sufficient to meet repository performance objectives relating to containment and isolation of the waste
- Provide reasonable expectation that future natural events (e.g. climate change, tectonics, seismicity, volcanism, diapirism) do not impair the containment and isolation properties of the candidate geologic system

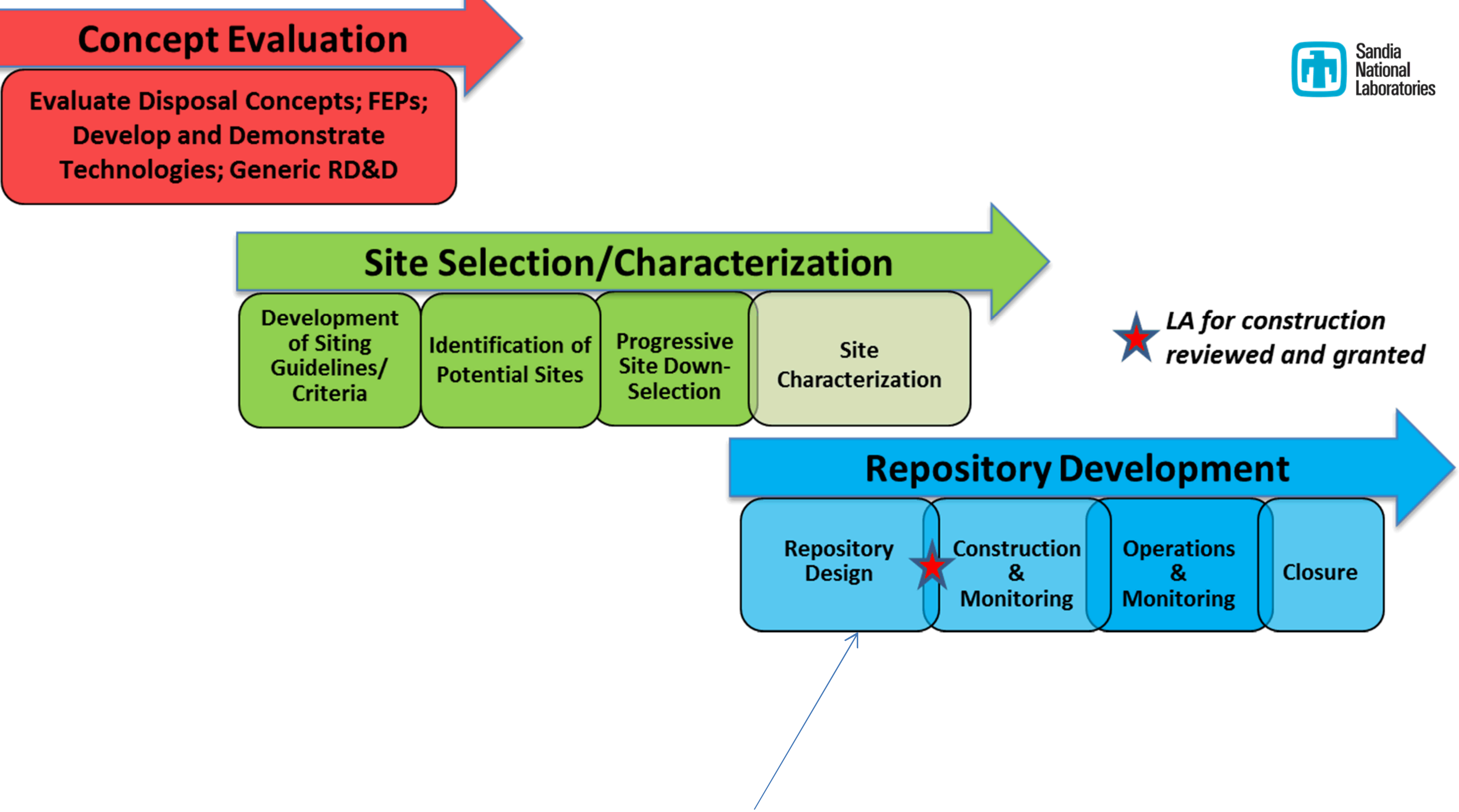


- Potential sites are identified through technical or sociopolitical means or a combination thereof
- Process uses technical and sociopolitical filters to go from one or more potential sites to the selected site
- Process continues in an iterative manner based on increasingly detailed site investigations and stakeholder interactions
- Increasingly detailed site investigations and associated stakeholder interactions are to assess the suitability of a site to safely host a deep geologic repository and to convey gathered information to stakeholders
- Selection of preferred site(s) generally requires both surface and subsurface investigations, a conceptual repository design, a preliminary safety assessment before the preferred site(s) and acceptance by stakeholders



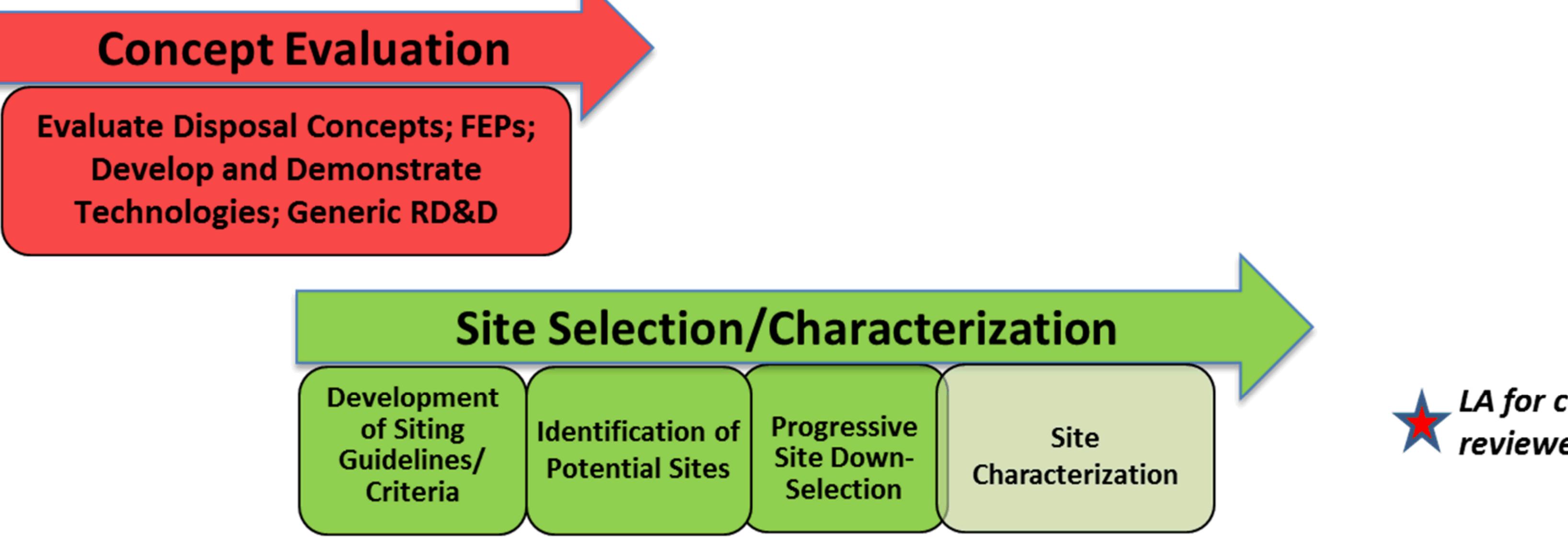
Goals of site characterization are to collect sufficient site-specific data to support:

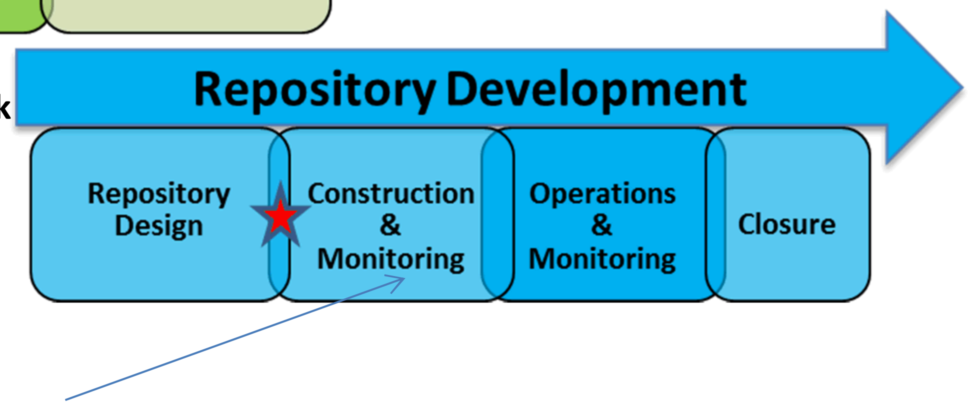
- **Integrated and confident descriptions of the site geology, hydrogeology, geochemistry, and geo-mechanical conditions**
- **Design of the repository**
- **Modeling and analysis of feature, events, and processes (FEPs)**
- **Characterization and reduction of uncertainties in important data and FEPs**



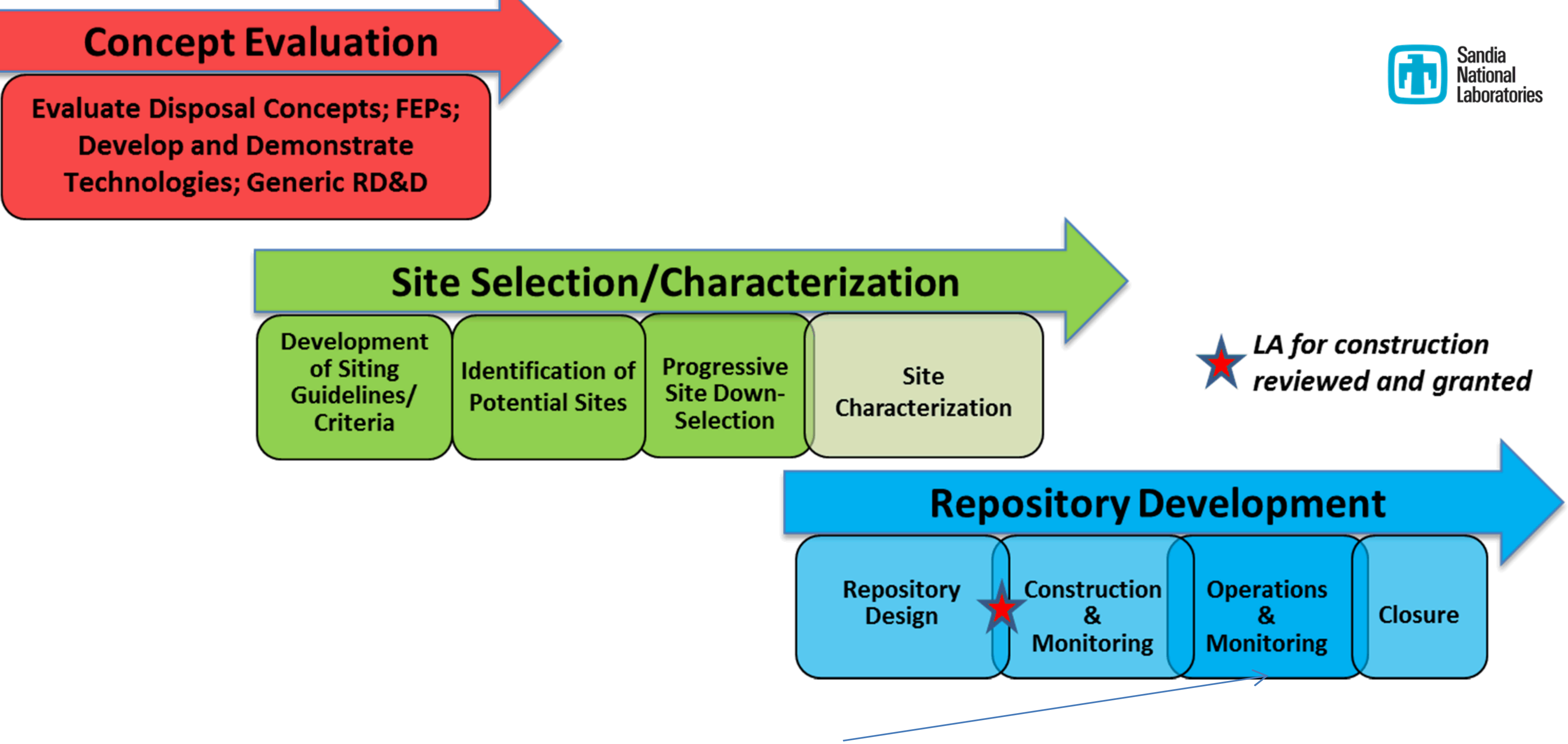
Goals of repository design are to:

- **Design a repository system that when coupled with the geologic system meets containment, isolation, and other post-closure requirements**
- **Design a system that has reasonable constructability and facilitates safe construction and safe operations and waste emplacement**





- If a construction authorization license is granted, work on repository surface and subsurface facilities begins
  - Excavate the access tunnels, access shafts, and ventilation shafts;
  - Mine the required waste handling areas, access and disposal tunnels in the host rock
  - Install electrical, safety, and ventilation systems
- Monitoring should be conducted to ensure that construction minimizes adverse impacts to the baseline conditions and geologic barrier



- Primary objective of repository operations is to transfer waste packages from the surface to their underground emplacement locations in a safe manner
- Radiation monitoring of the repository environment

Key Objectives of the Safety Case

- **Demonstrate sound understanding of the repository system – surface processes, engineered and geologic barriers, and biosphere**
- **Show how this understanding is the basis for the evaluation of <u>long-term performance and safety</u>**
- **Provide multiple lines of evidence that support the results of a safety assessment and understanding of the system**
- **Provide a framework to help plan and prioritize technical work as the repository program moves through the various phases of repository development**
- **Provide a vehicle to communicate the understanding of safety to a broad audience of stakeholders**
- **Quantify and substantiate with requisite confidence the safety of the repository**

Detailed Elements of the Safety Case

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Purpose and Context

Safety Strategy

Management Strategy
- Organizational/management structure
- Oversight groups / stakeholders
- Safety culture and QA
- Planning and work control
- Knowledge management

Siting and Design Strategy
- National laws (e.g., NWPA)
- Site selection methodology
- Socio-political acceptance
- Disposal concepts
- Design and engineering requirements
- Waste acceptance criteria
- Integration with storage and transportation

Assessment Strategy
- Regulations
- Safety goals/criteria
- Safety functions/multiple barriers
- Assessment methodologies
- R&D prioritization guidance

Assessment Basis

Pre-Closure Basis
- Repository design and layout
- Effects of excavation / construction methods
- Operational procedures
- Potential impact of external events
- Impact of pre-closure activities on post-closure safety

Site Selection Basis
- Consent-based siting considerations
- Evaluation of siting guidelines and criteria
- Selection of disposal concept
- FEP considerations
- Transportation considerations

Post-Closure Basis: Waste and Engineered Barriers
- Inventory characterization
- Waste form characterization
- Waste package characterization
- Buffer and backfill characterization
- Drift/room characterization
- Shafts/seals/liners characterization
- Potential impact of external events
- Assessment of uncertainties

Post-Closure Basis: Geosphere / Natural Barriers
- DRZ characterization
- Host rock characterization
- Other geologic unit characterization
- Potential impact of external events
- Assessment of uncertainties
- Synergy between natural and engineered barriers

Post-Closure Basis: Biosphere and Surface Environment
- Surface environment characteriz.
- Flora and fauna characterization
- Human behavior characterization

Safety Assessment

Pre-Closure Safety Analysis
- Initiating events and probabilities
- Event sequences
- Criticality analyses
- Dose and consequence analyses
- SSC identification

Post-Closure Performance Assessment
- FEP analysis
- Scenario development
- Model development
- Software/model validation
- Subsystem and barrier analyses
- PA model analyses
- Uncertainty and sensitivity analyses

Confidence Enhancement
- Evidence of system robustness
- Natural analogues
- Scientific observation/analysis
- Large-scale demonstrations
- Long-term extrapolation
- Detailed process modeling
- Peer review and collaboration

Synthesis and Conclusions
- Key findings and statement(s) of confidence
- Discussion/disposition of remaining uncertainties
- Path forward

Post-Closure Safety

- Isolate the waste from the accessible environment for thousands of years
- Contain the waste for thousands of years within the waste package and EBS
- Limit the amount of water entering and flowing through the EBS and contacting the waste packages and waste forms
- Limit and delay the movement of any radionuclides released from the waste packages
- Limit and delay the movement of radionuclides through the natural barrier system to the accessible environment

Elements of Performance Assessment

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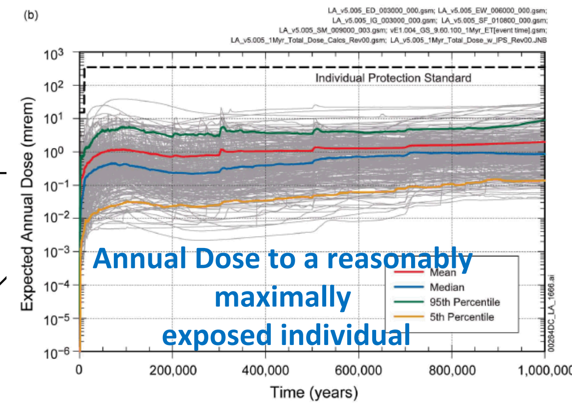
Biosphere
- Dilution
- Irrigation
- Water Consumption
- Dose Conversion Factors

Repository Design
- Location and layout
- No. and type of WPs
- EBS and Seals
- Thermal Loading and Ventilation

Near Field (EBS + DRZ)
- EBS Evolution
- DRZ Evolution
- Chemical Interactions
- Thermal Effects
- Mechanical Effects
- Flow and Transport

Performance Goal



Source Term
- RN Inventory
- WF Degradation
- WP Degradation
- Gas Generation
- RN Release

Far Field
- Flow and Transport
- Sorption
- RN Decay and Ingrowth

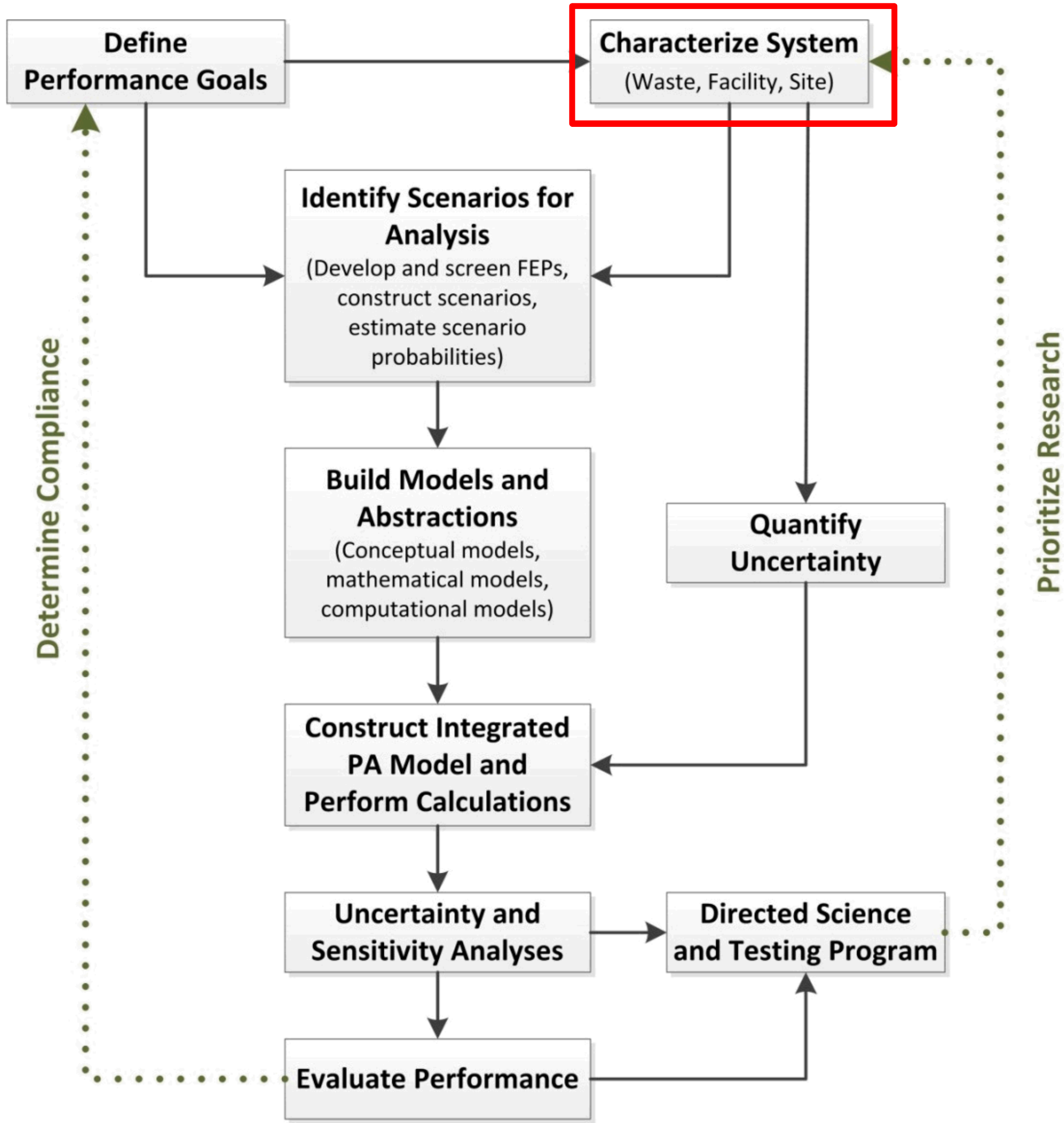
Natural System
- Climate
- Stratigraphy
- Hydrogeology
- Geochemistry
- Material properties
- Disruptive events

Engineered Barrier System (EBS)
Radionuclide (RN)
Waste Form (WF)
Waste Package (WP)
Disturbed Rock Zone (DRZ)

Role of Post-Closure Performance Assessment (PA)

- **PA is performed iteratively throughout the development of the repository assessment bases**
  - **Evaluate and synthesize the current scientific understanding and data for the given design concept or possible repository at a site**
  - **Understand and forecast long-term performance of the repository and identify factors that are most important to that performance**
  - **Identify factors and processes for which improved understanding or data are needed**
  - **Identify possible repository design modifications to improve performance or to reduce uncertainties**
  - **Demonstrate that the repository concept meets attendant regulatory requirements and will remain safe over the required timescale**
  - **Provide the framework around which integration among repository design, site characterization, and SA groups can be organized**

Performance Assessment Methodology



Characterizing the Repository System

- In developing an understanding of the repository system it is helpful to formulate and refine conceptual system models throughout the repository system characterization process
- The development of conceptual system models in iterative fashion with the PA model provides a structured approach to organize data, evaluate existing and new data, and identify and prioritize RD&D activities
- Development of conceptual models relies on the scientific method of investigation, which combines elements of both descriptive and hypothesis-based science
  - Descriptive science uses measurements/observations and data analyses to describe a system
  - Hypothesis-based science fills in knowledge gaps with scientific judgement - **a source of uncertainties**
  - Hypotheses are tested by making further observations and carrying out site and laboratory investigations – **to reduce uncertainties**

Example Questions to be Addressed by Site Characterization

- What units are of most hydrologic importance regionally?
- What units could be involved in release scenarios?
- What are the hydraulic gradients between units and potentiometric surfaces of the important units?
- What are the hydraulic properties of important units?
- What are the transport properties of units that might be involved in releases?
- What is the water chemistry of units that might be involved in releases? (subsequent presentation)

Conceptual Repository System and Property Models

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- Geology
  - Describes the stratigraphy, lithology, geological features, and evolution of the system to its current state and how it will evolve in the future
- Hydrogeology
  - Describes the hydrogeological units and features, conceptual understanding of flow in the different units and features, hydrological properties, recharge and discharge areas, and spatial and temporal changes in flow conditions
- Geochemistry
  - Describes the chemistry of the host rock and groundwater system
- Radionuclide Transport
  - Describes the conceptual understanding of transport processes through the different units and transport properties
- Engineered Barrier System
  - Describes the evolution of the engineered system components (including the waste package, waste forms, buffer/backfill, and near field) in addition to the thermal and chemical environments and the mobility and transport of radionuclides to the host rock

Conceptual Repository System and Property Models

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- **Engineered Material Properties**
  - **Provides physical and chemical properties of the engineered components for predicting their long-term performance**
- **Geo-mechanical Properties**
  - **Provides host rock geo-mechanical properties for design and predicting long-term response of the EBS**
- **Thermal Properties**
  - **Provides thermal properties for design and calculation of heat transfer into the host rock**

Planning R&D and Site Characterization Activities

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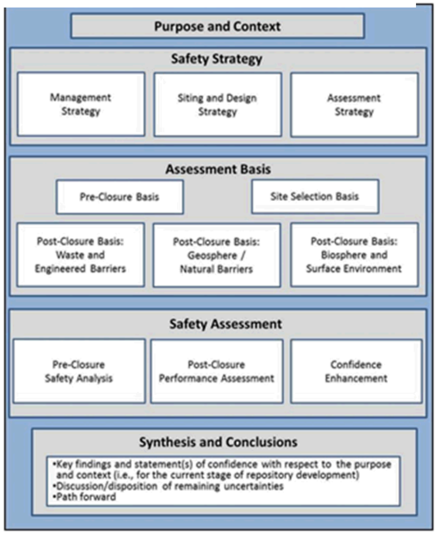
Primary challenges

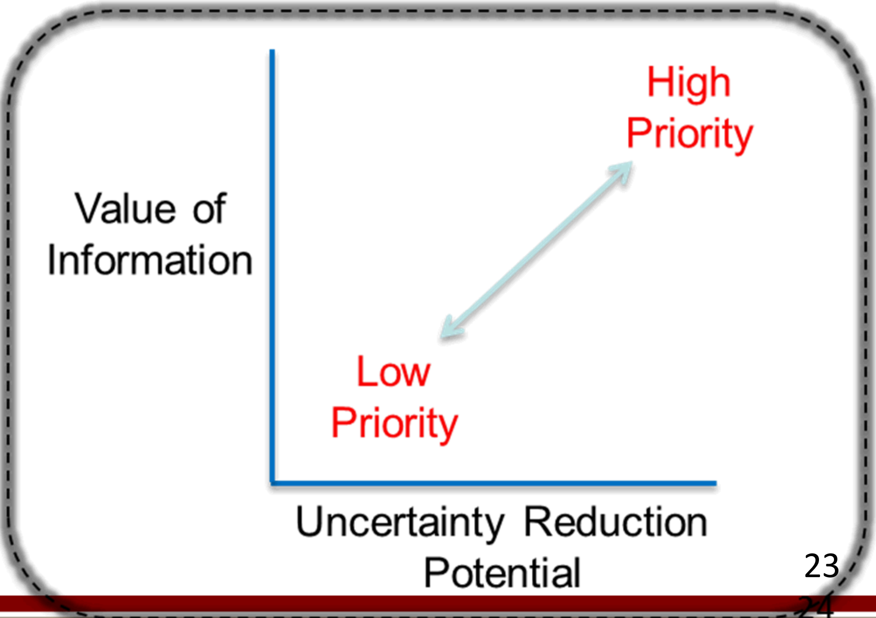
- Making decisions about where to focus and how to prioritize multiple site characterization and R&D activities
- Making decisions about what data and models will ultimately be required to assess the performance of the total repository system
- Making decisions about how much information is enough

Planning R&D and Site Characterization Activities

- R&D activities prioritized by
  - Potential to reduce uncertainties
  - Importance in demonstrating assessment bases
  - Importance in post-closure dose rate calculations
  - Other factors (e.g., cost, maturity of activity, redundancy, confidence building)



- Prioritization process can be formalized
  - Sensitivity Analysis
  - Decision Analysis



Decision Analysis

Formal quantitative methods of decision analysis exist for calculating the value of information associated with additional R&D and site characterization (see R. L. Keeney and H. Raiffa, Decisions with Multiple Objectives: Preferences and Value Trade-Offs), 1993.

1. Identify a set of objectives
2. Define metrics that can be used to evaluate how well an objective is met
3. Define an utility function to weight the importance of each metric and their scores
4. Evaluate each activity using the metrics
5. Sum the utility function results

Decisions on project priorities may be complicated by qualitative considerations.

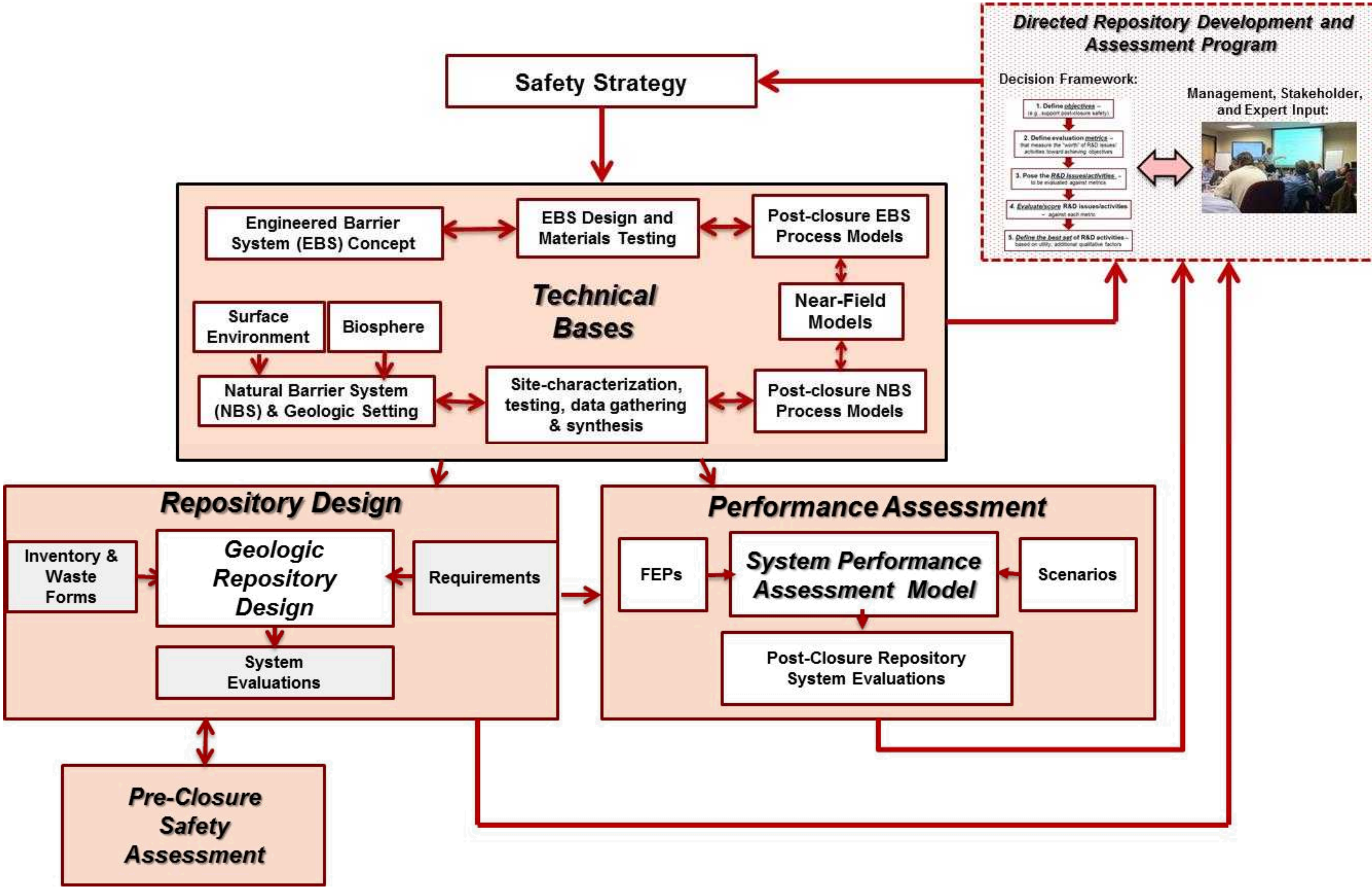
Decision Analysis cont.

Factors other than the quantitative sensitivity of the safety assessment/PA may be important to consider in the prioritization of data collection and analyses

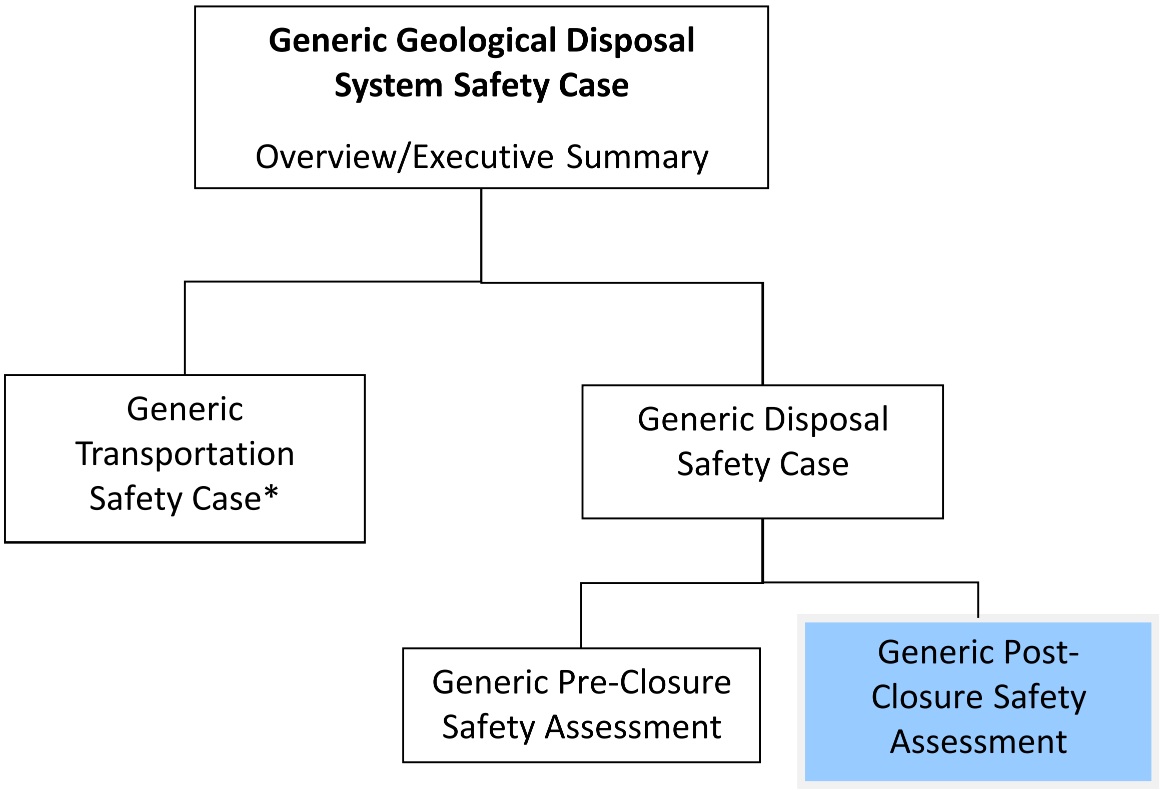
Public and political confidence in the repository system may require a minimum level of understanding for certain aspects of the system, regardless of the expected quantitative impact on performance

Some data collection tasks that have a high technical priority may also require long time frames, placing them in conflict with project schedule goals

Iterative Safety Case and Repository Development Process

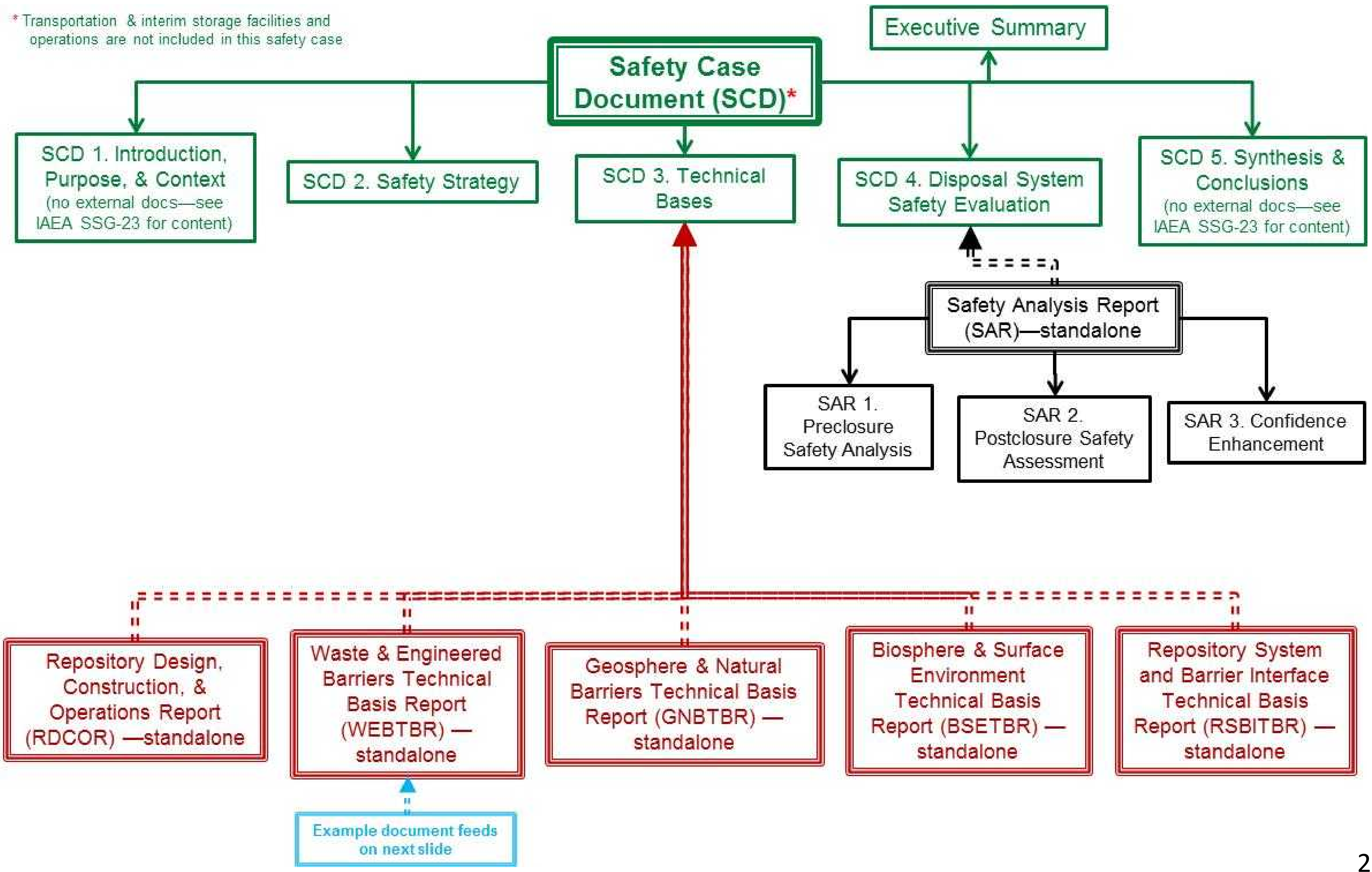


Example High-Level Documents

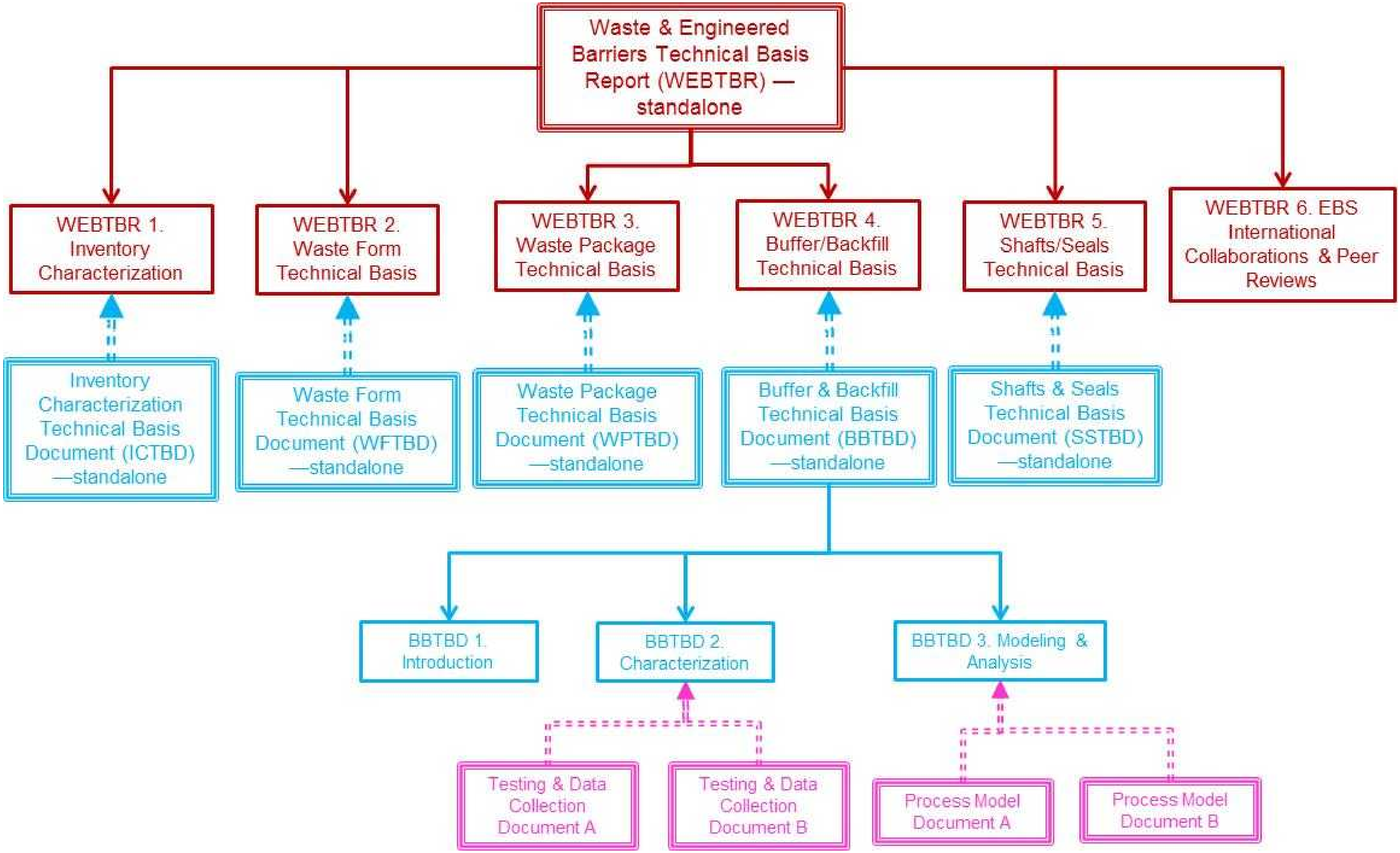


*Note: Although the proposed approach is for disposal research, a similar approach is recommended for the transportation system safety case.

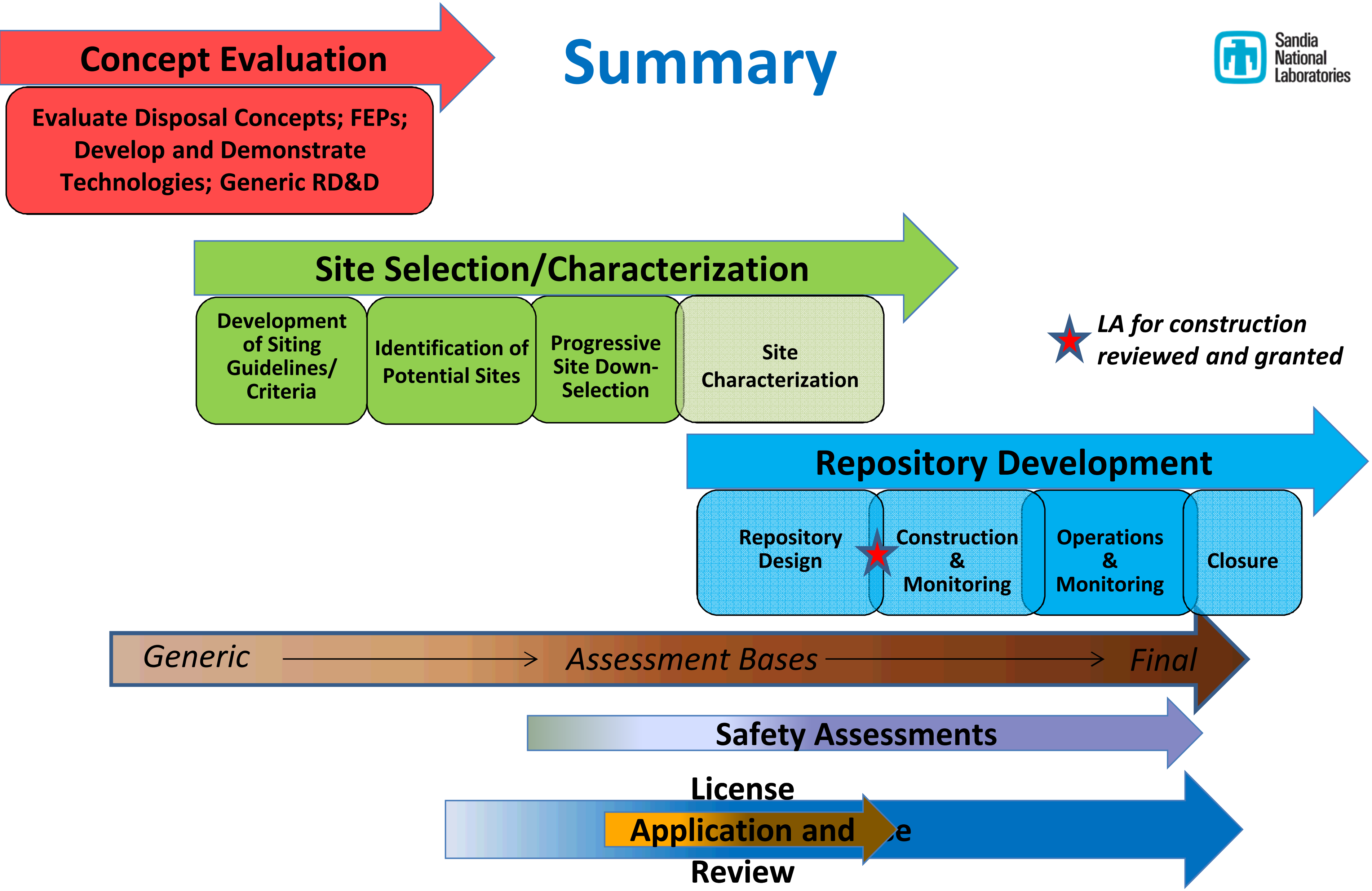
Example Documentation Structure of a Safety Case



Example Documentation Structure of a Safety Case (continued)



Summary



Concept Evaluation
Evaluate Disposal Concepts; FEPs; Develop and Demonstrate Technologies; Generic RD&D
Site Selection/Characterization
Development of Siting Guidelines/ Criteria
Identification of Potential Sites
Progressive Site Down-Selection
Site Characterization
LA for construction reviewed and granted
Repository Development
Repository Design
Construction & Monitoring
Operations & Monitoring
Closure
Generic
Assessment Bases
Final
Safety Assessments
License Application and Review

Summary (cont.)

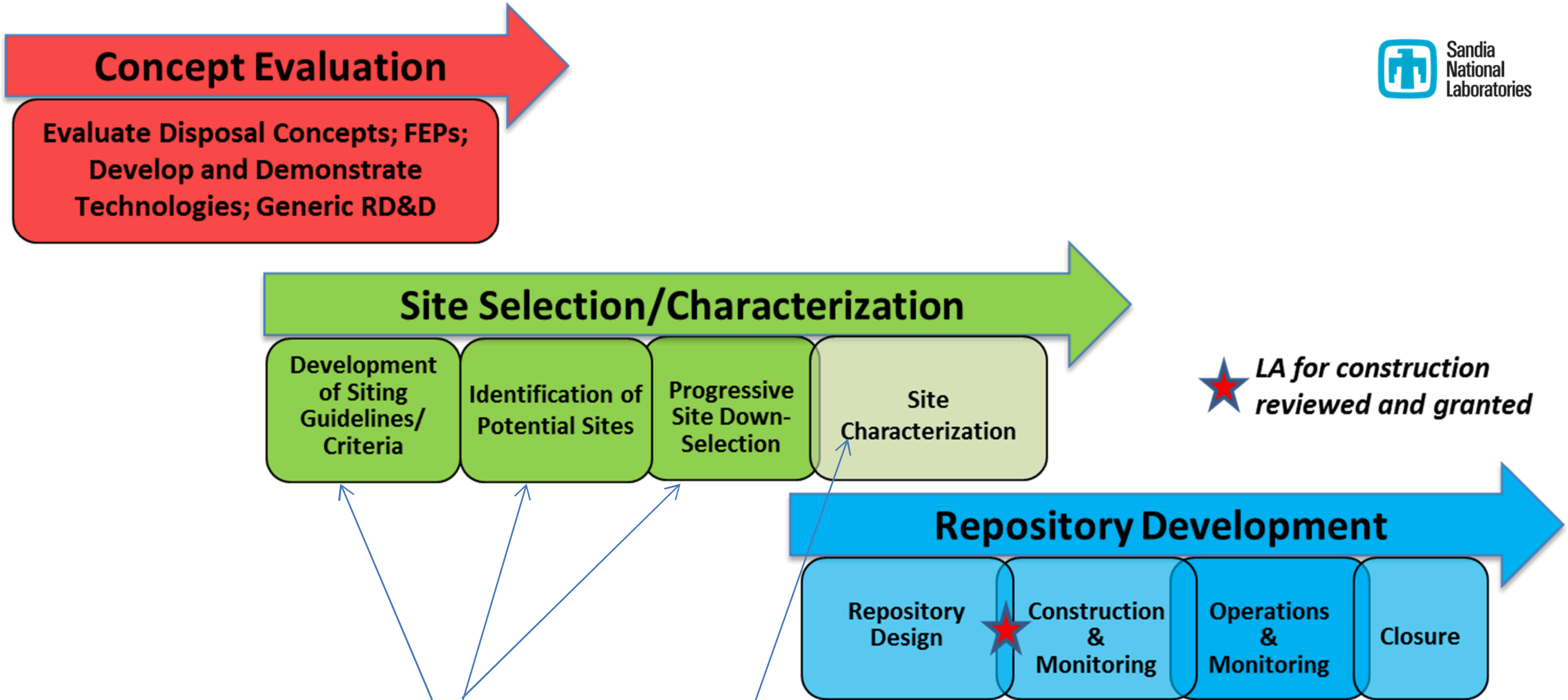
- **International experience *should* lessen the technical challenges with building a Safety Case and License Application**
- **Two Key Objectives of the Safety Case**
  - **Demonstrate sound understanding of the repository system – surface processes, engineered and geologic barriers, and biosphere**
  - **Show how this understanding is the basis for the evaluation of <u>long-term performance and safety</u>**
- **Development of the Safety Case is an iterative process**
  - **PA is the framework around which integration among repository design, site characterization, and PA groups can be organized**
- **Conceptual repository system models provide a framework to develop and document the assessment basis**
- **Prioritization of R&D and site characterization activities can be formalized using sensitivity analysis and decision analysis – <u>important to document basis for all decisions</u>**
- **Structure of the Safety Case should be developed early in the licensing process**

Thank you for your attention

Questions?

Outline

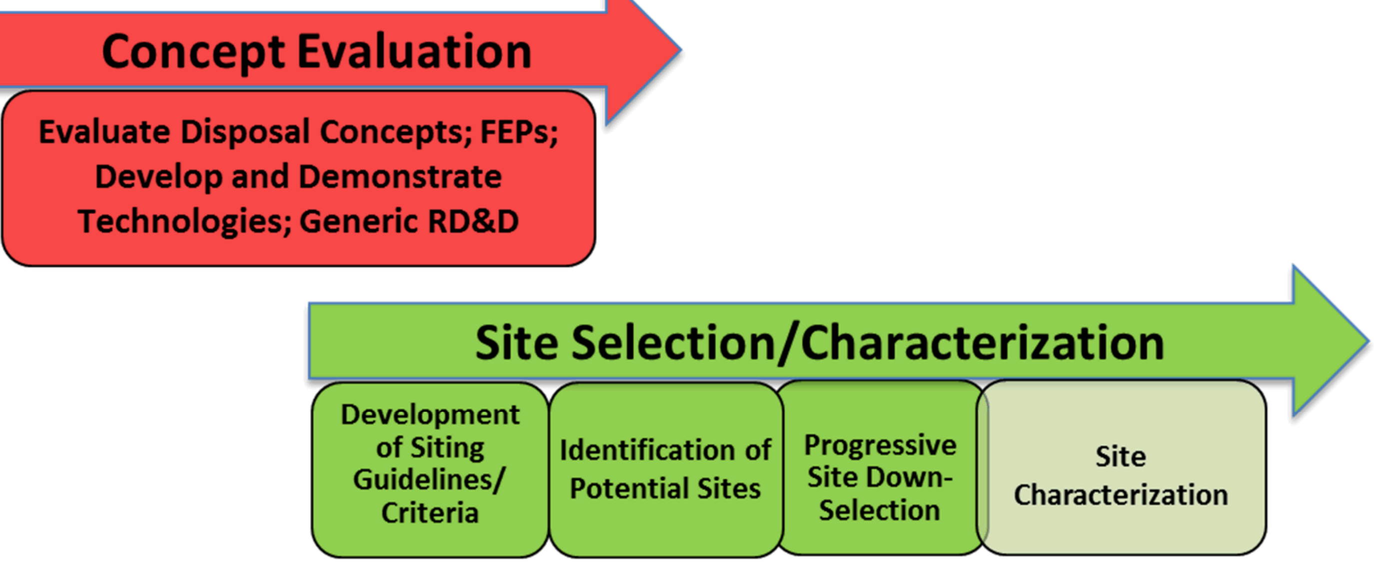
- What is the Safety Case and what is Safety Assessment?
- What is a deep geologic repository?
- Phases of repository development
- Key objectives and elements of the Safety Case
- Key elements of a post-closure Safety Assessment or Performance Assessment (PA)
- Characterizing the Repository System and Conceptual Repository System Models
- Prioritizing R&D and Site Characterization Activities
- Safety Case Documentation Structure
- Summary

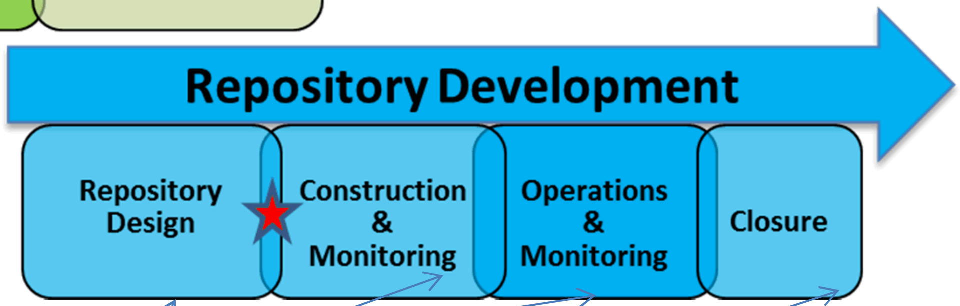


- Potential sites are identified through technical or social political means or a combination thereof
  - Exclude sites that have appreciable natural resources, are located on protected lands, or have cultural or ecological value
- Process uses technical and sociopolitical filters to go from one or more potential sites to the selected site
  - Provide reasonable expectation that the candidate site has geologic characteristics sufficient to meet repository performance objectives for containment and isolation of the waste
- Process continues in a iterative based on increasingly detailed site investigations and stakeholder interactions
  - Provide reasonable expectation that future natural events (e.g. climate change, tectonics, seismicity, volcanism, flooding) do not impair the containment and isolation properties of the candidate geologic system
- Increasingly detailed site investigations and stakeholder interactions are to assess the suitability of a site to safely host a deep geologic repository and to convey gathered information to stakeholders
- Selection of preferred site generally requires both surface and subsurface investigations, a conceptual repository design, a preliminary safety assessment before the preferred site(s) and acceptance by stakeholders

Goals of site characterization are to collect sufficient site-specific data to support:

- Integrated and confident descriptions of the site geology, hydrogeology, geochemistry, and geomechanical conditions
- Design of the repository
- Modeling and analyses of FEPs
- Characterization and reduction of uncertainties in important data and FEPs
- Safety assessments





- If a construction authorization license is granted, work on repository surface and subsurface facilities begins
  - Excavate the access tunnels, access shafts, and ventilation shafts;
  - Mine the required waste handling areas, access and disposal drifts in the host rock
  - Install electrical, safety, and ventilation systems
- Monitoring should be conducted to ensure that construction minimizes adverse impacts to the baseline conditions and geologic barrier

- Primary objective of repository operations is to transfer waste packages from the surface to their underground emplacement locations in a safe manner
- Radiation monitoring of the repository environment

- Closure of the subsurface repository involves backfilling and sealing of disposal drifts, handling areas, access tunnels and shafts
- If required an updated safety case would include new information and understanding of the repository and geosphere system gained during construction and operation periods

Goals of repository design are to:

- Design a repository system that when coupled with the geologic system meets containment, isolation, and other post-closure requirements
- Design a system that has reasonable constructability and facilitates safe construction and safe operations and waste emplacement