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Geologic Disposal Safety Assessment (GDSA): How GDSA Benefits from International Collaborations

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SAND2019 4103 PE

Geologic Disposal Safety Assessment (GDSA) Team

Thanks to GDSA team members

Jennifer Frederick, Glenn Hammond, Paul Mariner,
Dave Sevougian, Emily Stein

Sandia National Laboratories

And to the process modeling teams at

Los Alamos National Laboratory EST. 1943

Berkeley Lab

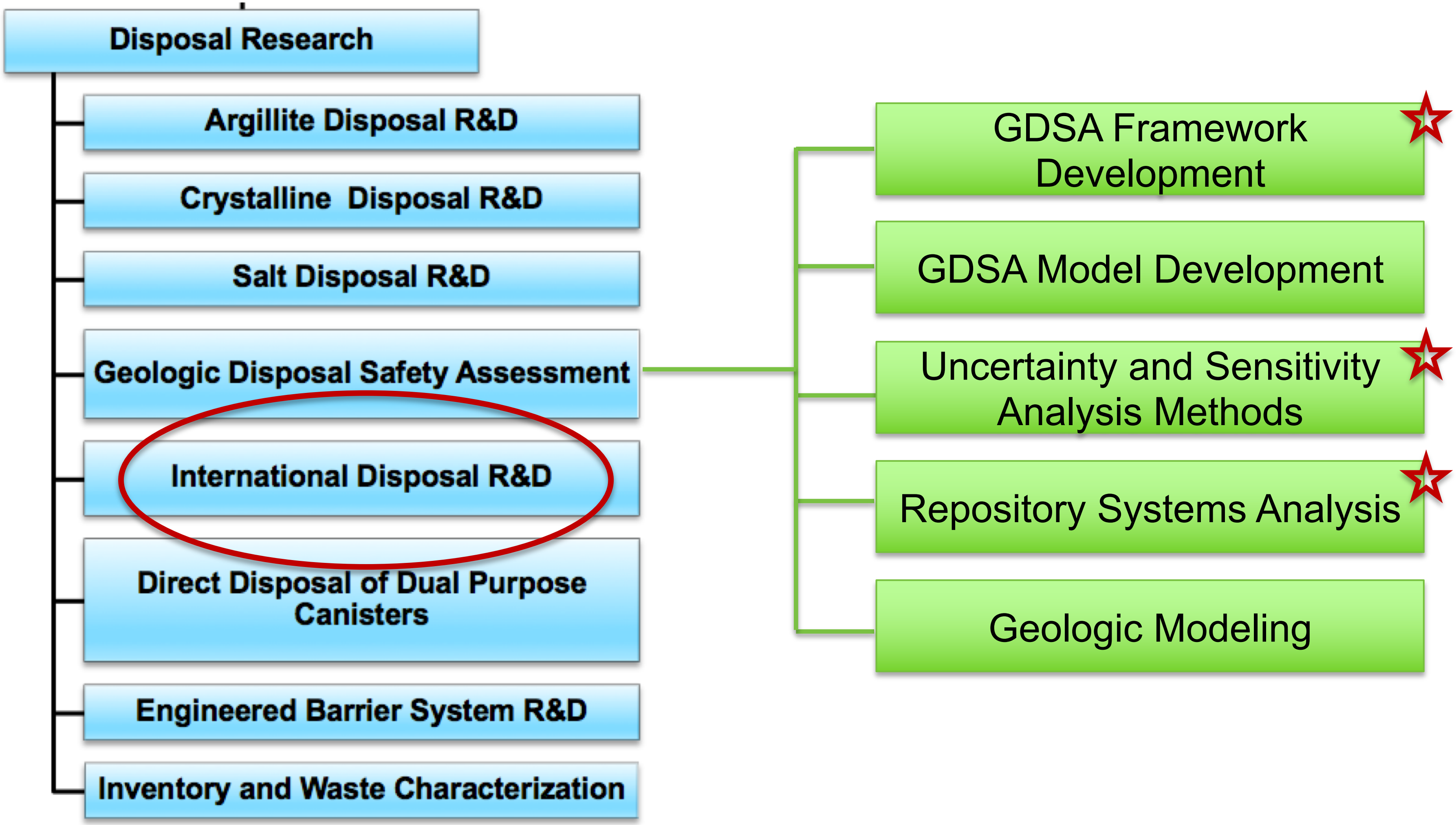
Lawrence Livermore

Argonne National Laboratory

Pacific Northwest National Laboratory

Geologic Disposal Safety Assessment

Work Scope

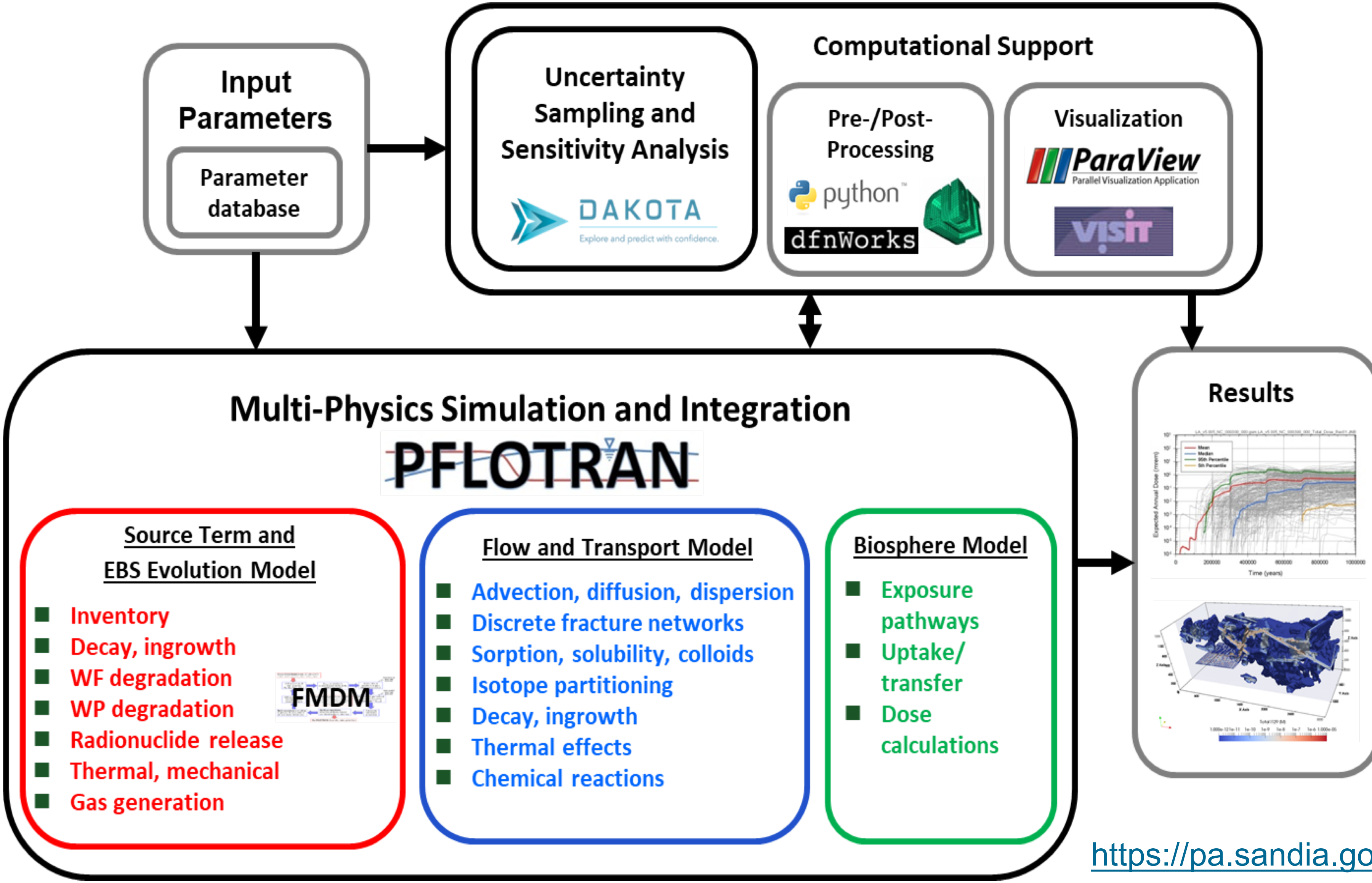


How GDSA Benefits from International Collaboration

- International datasets and concepts
  - Technical bases (Natural Barrier System (NBS), Disturbed Rock Zone (DRZ), Engineered Barrier System (EBS))
- Contributions to post-closure performance assessment (PA) models
  - Identify relevant Features, Events, and Processes (FEPs)
  - Process model development and validation
- Confidence enhancement
  - PA methodology in accordance with international standards of practice
  - Improve confidence in PA software through benchmarking, debugging, and demonstration on diverse problems
  - Expanded functionality through user contributions
  - State-of-the-art developments in methods and tools

GDSA Framework

Comprehensive software toolkit for post-closure performance assessment



https://pa.sandia.gov

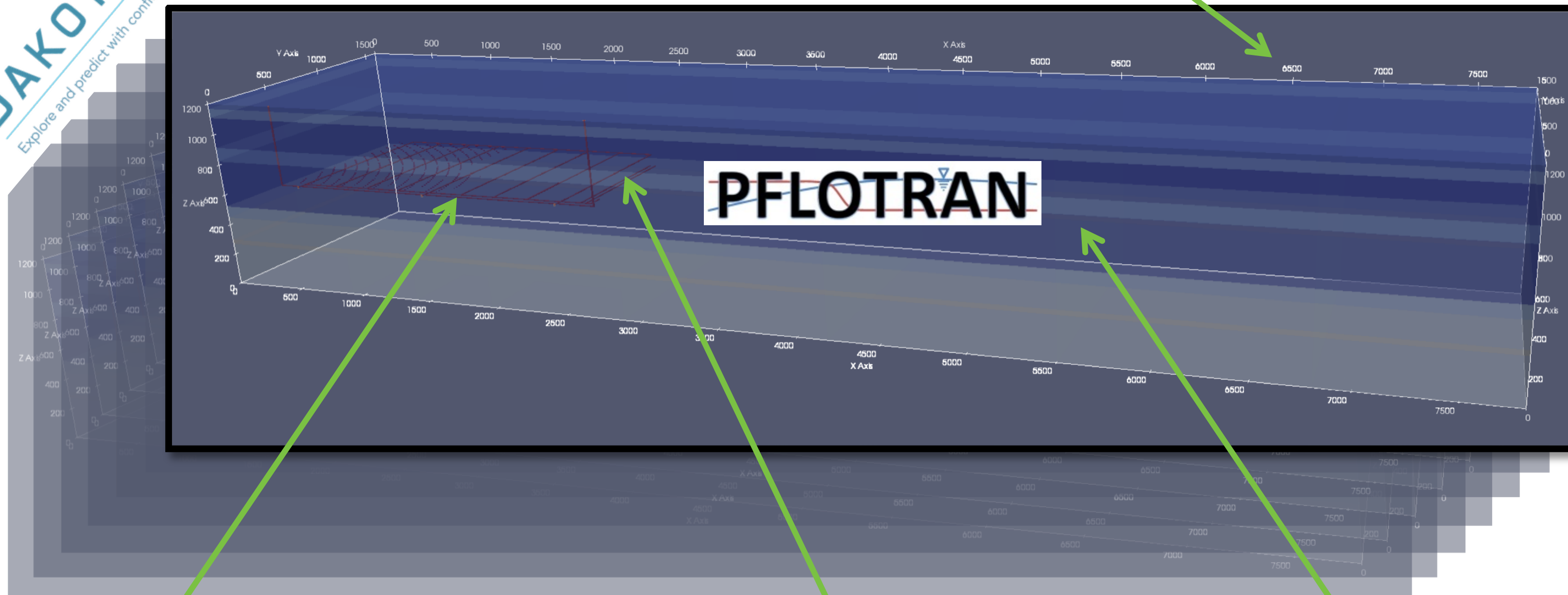
GDSA Framework

Comprehensive software toolkit for post-closure performance assessment

- PFLOTRAN development
  - Robust multiphase and high temperature capability
  - Coupled Sub-System Process Models
    - Engineered Barrier Processes ☆ **Jové Colón, Rutqvist, Zheng**
    - Near Field Perturbations ☆ **Kuhlman & Stauffer, Rutqvist**
    - Flow and Radionuclide Transport ☆ **Boukhalfa, Viswanathan**
- Quality Assurance
  - Software verification test suite
  - Regression and unit tests
  - Documentation
- International visibility and promotion ☆
  - Open source software development
  - PFLOTRAN short courses
  - Participation in international venues

Repository Systems Analysis

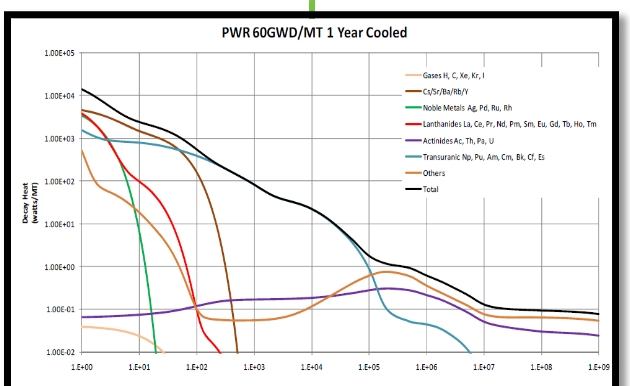
Biosphere

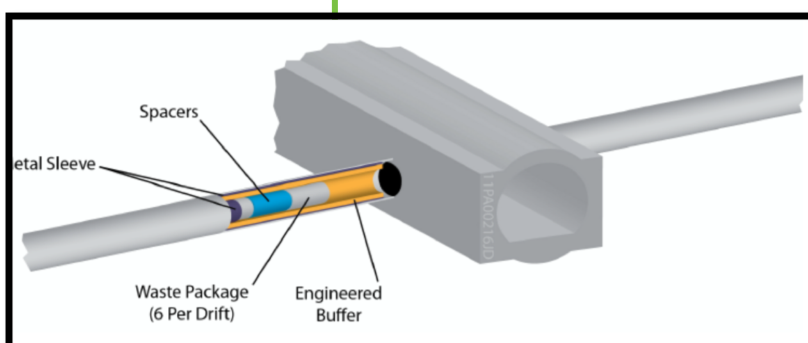


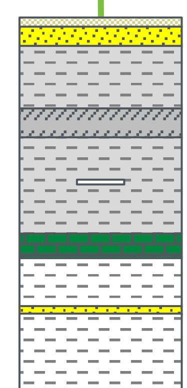
Waste Source Term

Engineered Barrier System

Natural Barrier System







Repository Systems Analysis

- Reference case concepts
  - Features/Events/Processes (FEPs)
  - Repository design/layout
  - Dual Purpose Canister disposal concepts
  - Technical bases for engineered and natural systems
- Total system simulations and probabilistic PA
- Near field simulations to facilitate process model coupling
- Relies on international datasets ☆

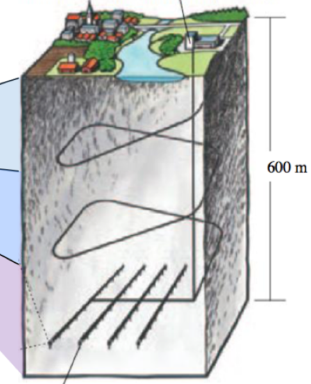
Reference Cases

1. Crystalline

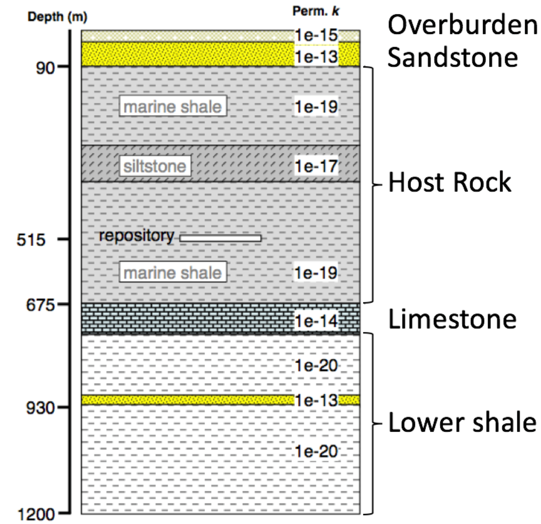
Table 2 Hydrogeological DFN parameters for each fracture domain, fracture set and depth zone

Fracture domain/elevation (m.a.s.l)[a]	Fracture set name	Orientation set pole: (trend, plunge), conc.	Size model, power-law (r_0, k_r) (m, −)	Intensity, (P_{32}), valid size interval: r_0 to 564 m (m^2/m^3)	Parameter values for the transmissivity models: Semi-correlated (a,b,σ)	Correlated (a,b)	Uncorrelated (μ,σ)
FFM01 and FFM06>−200	NS	(292, 1) 17.8	(0.038, 2.50)	0.073	$6.3 \cdot 10^{-9}$, 1.3, 1.0	$6.7 \cdot 10^{-9}$, 1.4	−6.7, 1.2
	NE	(326, 2) 14.3	(0.038, 2.70)	0.319			
	NW	(60, 6) 12.9	(0.038, 3.10)	0.107			
	EW	(15, 2) 14.0	(0.038, 3.10)	0.088			
	HZ	(5, 86) 15.2	(0.038, 2.38)	0.543			
FFM01 and FFM06 −200 to −400	NS	(292, 1) 17.8	(0.038, 2.50)	0.142	$1.3 \cdot 10^{-9}$, 0.5, 1.0	$1.6 \cdot 10^{-9}$, 0.8	−7.5, 0.8
	NE	(326, 2) 14.3	(0.038, 2.70)	0.345			
	NW	(60, 6) 12.9	(0.038, 3.10)	0.133			
	EW	(15, 2) 14.0	(0.038, 3.10)	0.081			
	HZ	(5, 86) 15.2	(0.038, 2.38)	0.316			
FFM01 and FFM06<−400	NS	(292, 1) 17.8	(0.038, 2.50)	0.094	$5.3 \cdot 10^{-11}$, 0.5, 1.0	$1.8 \cdot 10^{-10}$, 1.0	−8.8, 1.0
	NE	(326, 2) 14.3	(0.038, 2.70)	0.163			
	NW	(60, 6) 12.9	(0.038, 3.10)	0.098			
	EW	(15, 2) 14.0	(0.038, 3.10)	0.039			
	HZ	(5, 86) 15.2	(0.038, 2.38)	0.141			
FFM02>−200	NS	(83, 10) 16.9	(0.038, 2.75)	0.342	$9.0 \cdot 10^{-9}$, 0.7, 1.0	$5.0 \cdot 10^{-9}$, 1.2	−7.1, 1.1
	NE	(143, 9) 11.7	(0.038, 2.62)	0.752			
	NW	(51, 15) 12.1	(0.038, 3.20)	0.335			
	EW	(12, 0) 13.3	(0.038, 3.40)	0.156			
	HZ	(71, 87) 20.4	(0.038, 2.58)	1.582			
FFM03, FFM04 and FFM05>−400	NS	(292, 1) 17.8	(0.038, 2.60)	0.091	$1.3 \cdot 10^{-8}$, 0.4, 0.8	$1.4 \cdot 10^{-8}$, 0.6	−7.2, 0.8
	NE	(326, 2) 14.3	(0.038, 2.50)	0.253			
	NW	(60, 6) 12.9	(0.038, 2.55)	0.258			
	EW	(15, 2) 14.0	(0.038, 2.40)	0.097			
	HZ	(5, 86) 15.2	(0.038, 2.55)	0.397			
FFM03, FFM04 and FFM05<−400	NS	(292, 1) 17.8	(0.038, 2.60)	0.102	$1.8 \cdot 10^{-8}$, 0.3, 0.5	$7.1 \cdot 10^{-9}$, 0.6	−7.2, 0.8
	NE	(326, 2) 14.3	(0.038, 2.50)	0.247			
	NW	(60, 6) 12.9	(0.038, 2.55)	0.103			
	EW	(15, 2) 14.0	(0.038, 2.40)	0.068			
	HZ	(5, 86) 15.2	(0.038, 2.55)	0.250			

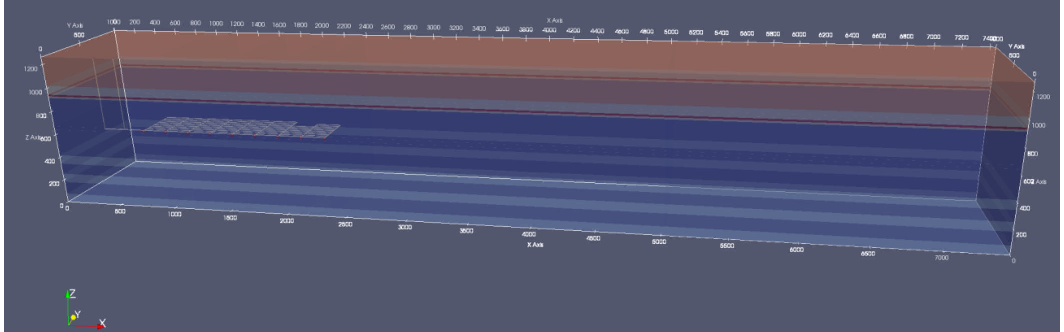
[a] Meters above sea level



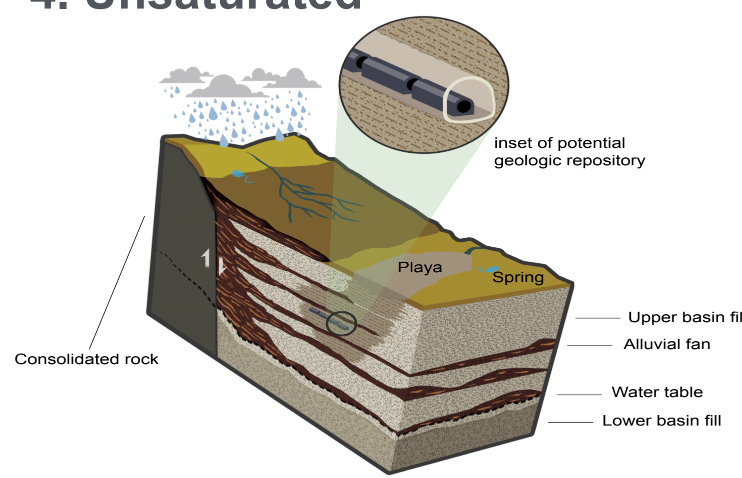
2. Shale



3. Salt



4. Unsaturated



Uncertainty Quantification and Sensitivity Analysis (UQ/SA)

- Implementation and application of uncertainty and sensitivity analysis methods
  - Effective methods for computationally expensive problems
  - Which methods return the most information on which problems?
- Feed back to research and development (R&D)
  - Which uncertain inputs contribute the most to uncertainty in the output?
  - Which uncertain inputs have little to no influence on output uncertainty?
- International collaboration ☆
  - Exchange knowledge
  - Compare software and methods
  - Develop joint approach to sensitivity analysis

1. Introduction, Purpose, and Context

2. Safety Strategy

2.1 Management Strategy

a. Organizational/mgmt. structure
b. Safety culture & QA
c. Planning and Work Control
d. Knowledge management
e. Oversight groups

2.2 Siting & Design Strategy

a. National laws
b. Site selection basis & robustness
c. Design requirements
d. Disposal concepts
e. Intergenerational equity

2.3 Assessment Strategy

a. Regulations and rules
b. Performance goals/safety criteria
c. Safety functions/multiple barriers
d. Uncertainty characterization
e. RD&D prioritization guidance

3. Technical Bases

3.1 Site Selection

a. Siting methodology
b. Repository concept selection
c. FEPs Identification
d. Technology development
e. Transportation considerations
f. Integration with storage facilities

3.2 Pre-closure Basis

a. Repository design & layout
b. Waste package design
c. Construction requirements & schedule
d. Operations & surface facility
e. Waste acceptance criteria
f. Impact of pre-closure activities on post-closure

3.3 Post-closure Bases (FEPs)

3.3.1 Waste & Engineered Barriers Technical Basis

a. Inventory characterization
b. WF/WP technical basis
c. Buffer/backfill technical basis
d. Shafts/seals technical basis
e. UQ (aleatory, epistemic)

3.3.2 Geosphere/ Natural Barriers Technical Basis

a. Site characterization
b. Host rock/DRZ technical basis
c. Aquifer/other geologic units technical basis
d. UQ (aleatory, epistemic)

3.3.3 Biosphere Technical Basis

a. Biosphere & surface environment:
- Surface environment
- Flora & fauna
- Human behavior

4. Disposal System Safety Evaluation

4.1 Pre-closure Safety Analysis

a. Surface facilities and packaging
b. Mining and drilling
c. Underground transfer and handling
d. Emplacement operations
e. Design basis events & probabilities
f. Pre-closure model/software validation
g. Criticality analyses
h. Dose/consequence analyses

4.2 Post-closure Safety Assessment

a. FEPs analysis/screening
b. Scenario construction/screening
c. PA model/software validation
d. Barrier/safety function analyses and subsystem analyses
e. PA and Process Model Analyses/Results
f. Uncertainty characterization and analysis
g. Sensitivity analyses

4.3 Confidence Enhancement

a. R&D prioritization
b. Natural/anthropogenic analogues
c. URL & large-scale demonstrations
d. Monitoring and performance confirmation
e. International collaboration & peer review
f. Verification, validation, transparency
g. Qualitative and robustness arguments

5. Synthesis & Conclusions

a. Key findings and statement(s) of confidence
b. Discussion/disposition of remaining uncertainties
c. Path forward

Safety Case Component 3.3: Post-closure Technical Bases

3.3 Post-closure Bases (FEPs)

3.3.1 Waste & Engineered Barriers Technical Basis

a. Inventory characterization
b. Waste form/waste package technical basis
c. Buffer/backfill technical basis
d. Shafts/seals technical basis
e. UQ (aleatory, epistemic)

3.3.2 Geosphere/ Natural Barriers Technical Basis

a. Site characterization
b. Host rock/DRZ technical basis
c. Aquifer/other geologic units technical basis
d. UQ (aleatory, epistemic)

International datasets contribute to GDSA generic reference cases.

Crystalline Reference Case – Natural Barrier System Technical Basis

Feature, Process	International Influences	URL / Site	References
Reference case site concept	Sweden	Forsmark	SKB 2007; 2008 Mariner et al. 2016
Fracture distribution	Sweden	Forsmark	Follin et al. 2014; Joyce et al. 2014; Wang et al. 2014; Mariner et al. 2016
Crystalline matrix permeability and porosity	Switzerland, Canada, Korea	Grimsel, Lac du Bonnet, KURT	Schild et al. 2001; Martino & Chandler 2004; Cho et al. 2013; Mariner et al. 2016
Effective diffusion coefficient	Switzerland	Grimsel	Soler et al. 2015; Mariner et al. 2016
DRZ permeability and extent	Canada, Korea	Lac du Bonnet, KURT	Martino & Chandler 2004; Cho et al. 2013; Mariner et al. 2016
Geochemical Environment	Sweden, Finland, Canada	Forsmark, Olkiluoto, Canadian Shield	SKB 2006; Posiva 2010; Mariner et al. 2011

Crystalline Reference Case – Engineered Barrier System Technical Basis

Feature, Process	International Influences	References
Spent Nuclear Fuel Dissolution	Sweden	SKB 2006; Sassani et al. 2016
Bentonite Buffer Concepts	Korea, etc.	Choi and Choi 2008; Wang et al. 2014; Mariner et al. 2016
Bentonite Thermal Conductivity	Germany, China	Jobmann & Buntebarth 2009; Wang et al. 2015; Mariner et al. 2016
Bentonite Porosity and Permeability	France	Liu et al. 2016; Mariner et al. 2016
Bentonite Adsorption Distribution Coefficients (K_ds)	Sweden	SKB 2004; Mariner et al. 2011

Safety Case Component 4.2: Post-closure Safety Assessment

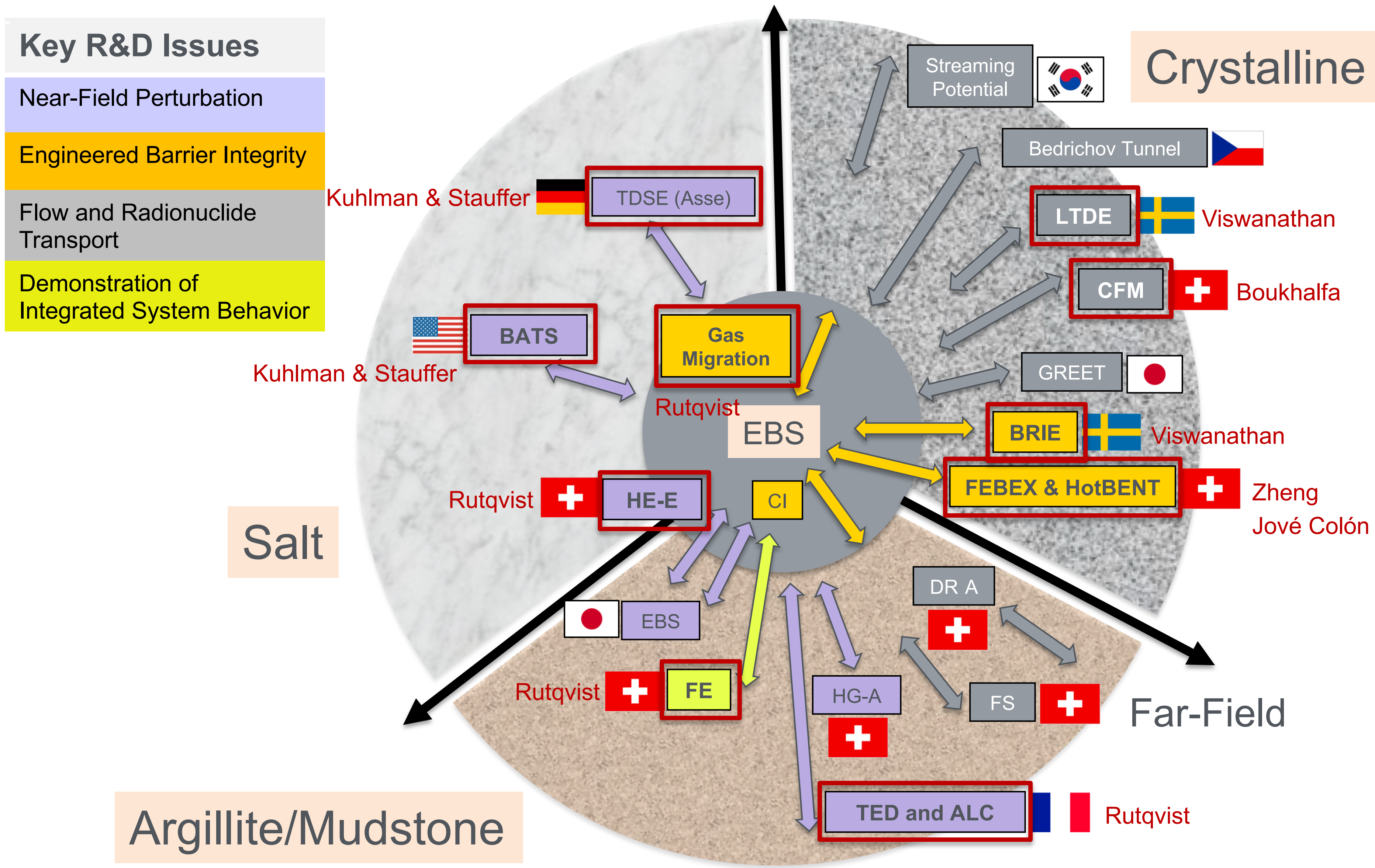
4.2 Post-closure Safety Assessment

a. FEPs analysis/screening
b. Scenario construction/screening
c. PA model/software validation
d. Barrier/safety function analyses and subsystem analyses
e. PA and Process Model Analyses/Results
f. Uncertainty characterization and analysis
g. Sensitivity analyses

International collaboration contributes directly to GDSA models and concepts.

International collaboration increases confidence in GDSA tools and methods.

International URL Portfolio in a Nutshell



Crystalline Reference Case – Colloid Formation and Migration (CFM)

International URL Collaboration:

- **C**olloid **F**ormation and **M**igration (CFM) – colloidal transport experiments at Grimsel Test Site and related laboratory experiments

How GDSA benefits:

- Identify kinetic and equilibrium regimes that result in significant colloid-facilitated transport over long time and distance scales
- Integration of generalized colloidal transport model

Key R&D Issue:

Flow and Radionuclide Transport

Grimsel

Boukhalfa

Crystalline Reference Case – BRIE, LTDE

International URL Collaborations

- **B**entonite **R**ock **I**nteraction **E**xperiment (BRIE) – at the Äspö Hard Rock Laboratory
- **L**ong **T**erm **D**iffusion **E**xperiment (LTDE) at Grimsel Test Site

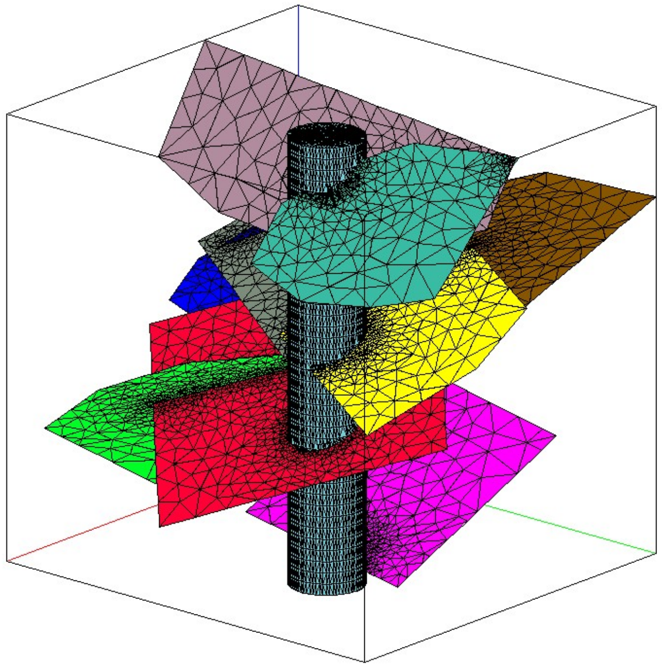
How GDSA benefits:

- Conceptual models for bentonite saturation in fractured rock and diffusive transport in the DRZ
- Models and methods for simulation of flow and transport in fractured rock

Key R&D Issues:

Flow and Radionuclide Transport

Engineered Barrier Integrity



Courtesy of Hari Viswanathan

Viswanathan

Clay/Shale Reference Case – Mont Terri and Bure heater tests

International URL Collaborations

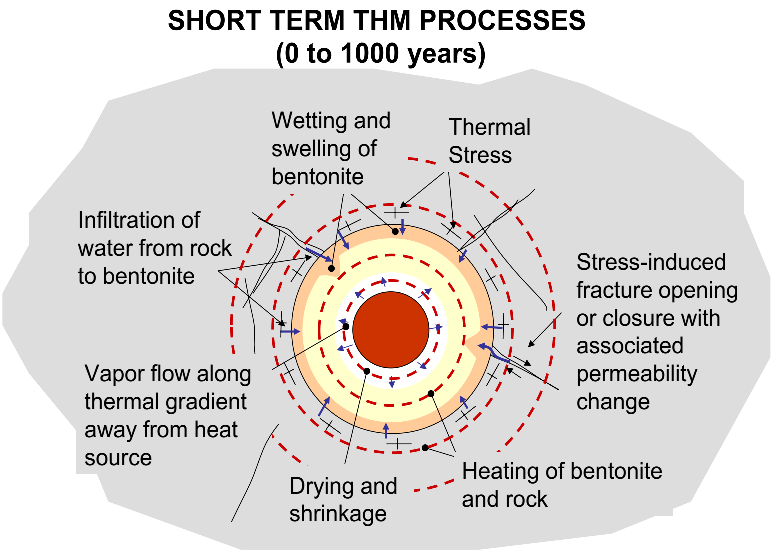
- Half-scale and full-scale heater emplacement tests at Mont Terri (Opalinus Clay)
- Heater tests at Bure (Callovo-Oxfordian Argillite)

How GDSA benefits:

- Conceptual model for mutual evolution of DRZ and buffer
- Integrate emulator(s) for Thermal Hydrological Mechanical (THM) evolution of buffer and DRZ in clay/shale repository

Key R&D Issues:

Near Field Perturbation



Courtesy of J. Rutqvist

Rutqvist

Salt Reference Case – BATS, Asse Mine Heater Test

International URL Collaborations

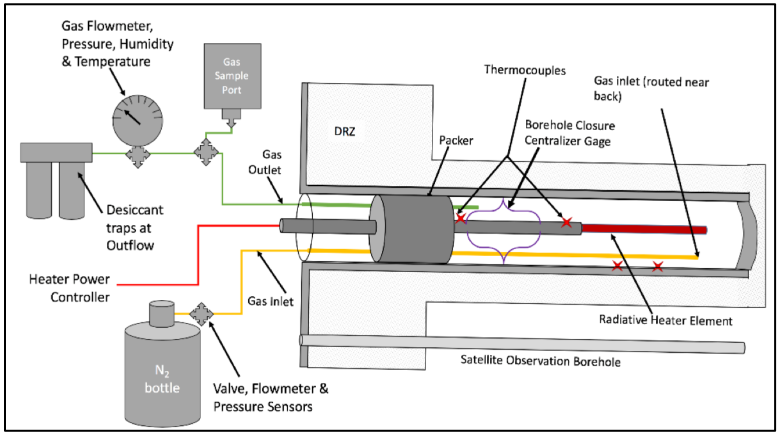
- **B**rine **A**vailability **T**est in **S**alt (BATS) - heater test in the Waste Isolation Pilot Plant
- Asse Mine heater test – salt creep and consolidation to validate THM constitutive laws

How GDSA benefits:

- Conceptual models for salt creep, evolution of porosity and permeability, gas and brine migration with heat
- Integrate emulator(s) for THMC evolution of backfill and DRZ

Key R&D Issues:

Near Field Perturbation



Courtesy of Kris Kuhlman

Kuhlman & Stauffer

Engineered Barrier System – FEBEX-DP and HotBENT

International URL Collaborations

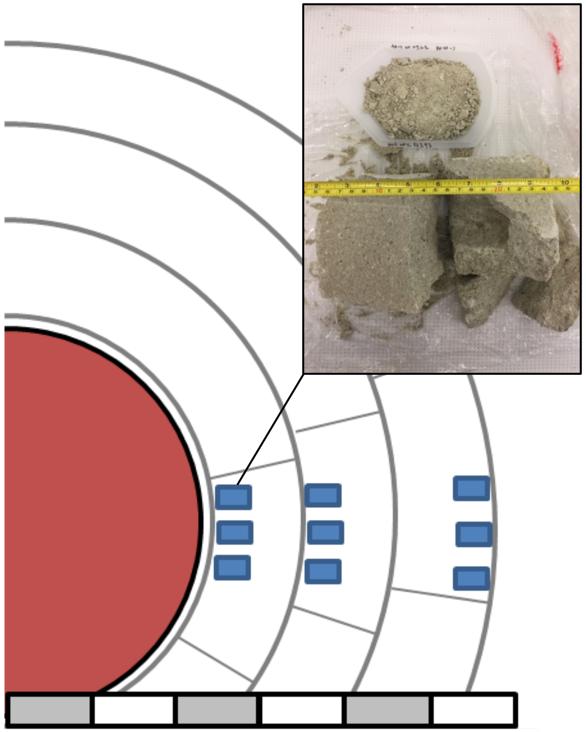
- **F**ull-Scale **E**ngineered **B**arrier **Ex**periment-**D**ismantling **P**roject and HotBENT – heater tests in bentonite at Grimsel Test Site

How GDSA benefits:

- Identify processes affecting evolution of engineered barrier properties
- Establish thermal limits for buffer integrity
- Integrate emulator(s) for THMC evolution of the buffer

Key R&D Issue:

Engineered Barrier Integrity



Courtesy of Carlos Jové Colón

Zheng
Jové Colón

Engineered Barrier System – DECOVALEX gas migration

International URL Collaborations

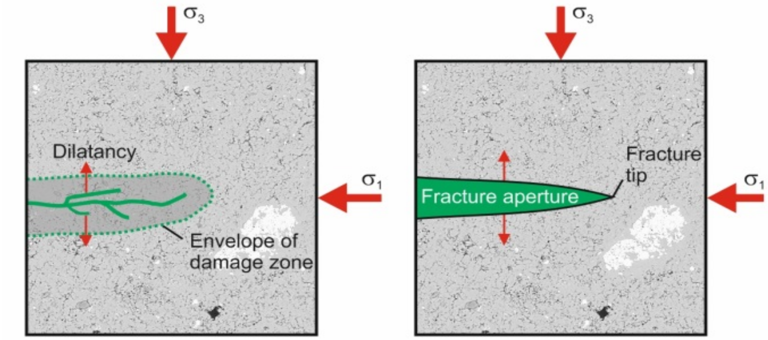
- Gas injection experiment in low-permeability porous media (bentonite, shale)
- Planned field scale study at Mont Terri (DECOVALEX 2023)

How GDSA benefits:

- Conceptual model(s) for gas migration in bentonite and its effect on bentonite permeability
- Permeability (upscaled) as a function of gas pressure

Key R&D Issue:

Engineered Barrier Integrity

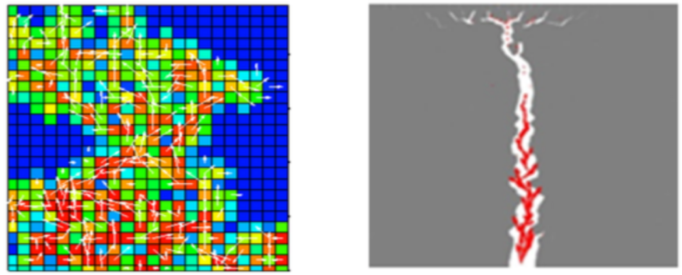


Dilatancy controlled gas flow ("pathway dilation")

Gas transport in tensile fractures ("hydro-/gasfrac")

1) Continuum model approach using TOUGH-FLAC

2) Discrete fracture model approach using TOUGH-RBSN



Rutqvist et al. 2018

Rutqvist

Safety Case Component 4.3: Confidence Enhancement

4.3 Confidence Enhancement

a. R&D prioritization
b. Natural/anthropogenic analogues
c. URL & large-scale demonstrations
d. Monitoring and performance confirmation
e. International collaboration & peer review
f. Verification, validation, transparency
g. Qualitative and robustness arguments

International collaboration increases confidence in GDSA tools and methods.

GDSA International Outreach and Collaborations

- U.S./Germany Salt Collaboration
  - Development of comprehensive FEPs database
  - PA software benchmark comparison
- International Uncertainty Quantification and Sensitivity Analysis Collaboration
  - Contribute expertise to international discussion
  - Develop joint approach to sensitivity analysis
- DECOVALEX 2023 PA Proposal
- PFLOTRAN support for repository PA programs (on-going w/ Taiwan, Australia)
  - Testing and demonstration on diverse problems
- Open source development
  - Transparency
  - Expanded functionality

How GDSA Benefits from International Collaboration

- International datasets and concepts
  - Technical bases (Natural Barrier System (NBS), Disturbed Rock Zone (DRZ), Engineered Barrier System (EBS))
- Contributions to post-closure performance assessment (PA) models
  - Identify relevant Features, Events, and Processes (FEPs)
  - Process model development and validation
- Confidence enhancement
  - PA methodology in accordance with international standards of practice
  - Improve confidence in PA software through benchmarking, debugging, and demonstration on diverse problems
  - Expanded functionality through user contributions
  - State-of-the-art developments in methods and tools

Questions?

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