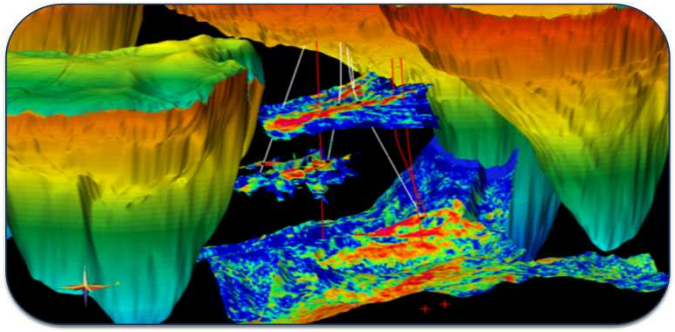
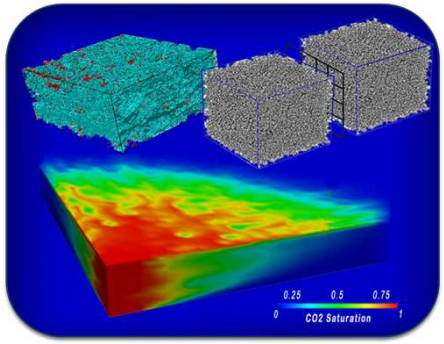
SAND2015-3622C

Exceptional service in the national interest

Sandia National Laboratories





Geomechanics Issues Regarding Heat-Generating Waste Disposal in Salt

Hansen, F. D.
Sandia National Laboratories, Albuquerque, New Mexico, USA
Popp, T.
Institut für Gebirgsmechanik (IfG), Leipzig, Germany

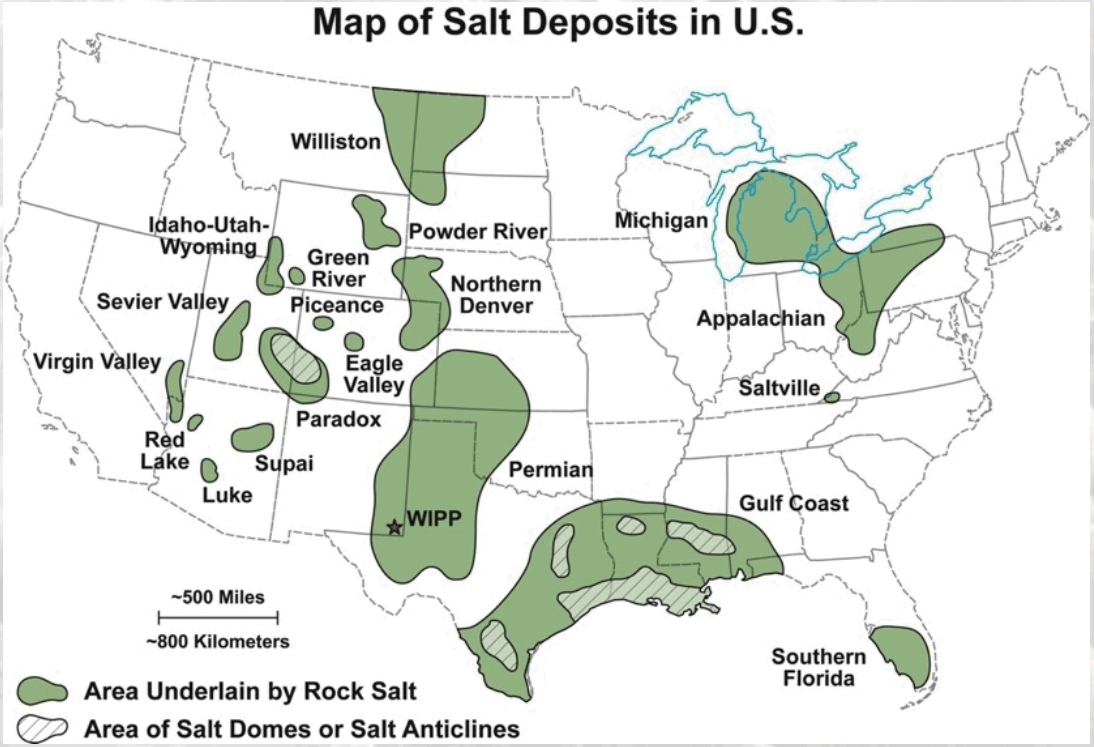
ARMA Conference 2015

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2015-1251 PE.

Salt Disposal Investigations

… Salt is an Ideal Disposal Medium



"Salt at great depth 'flows.' It will encapsulate waste and isolate it from the surface for eons."

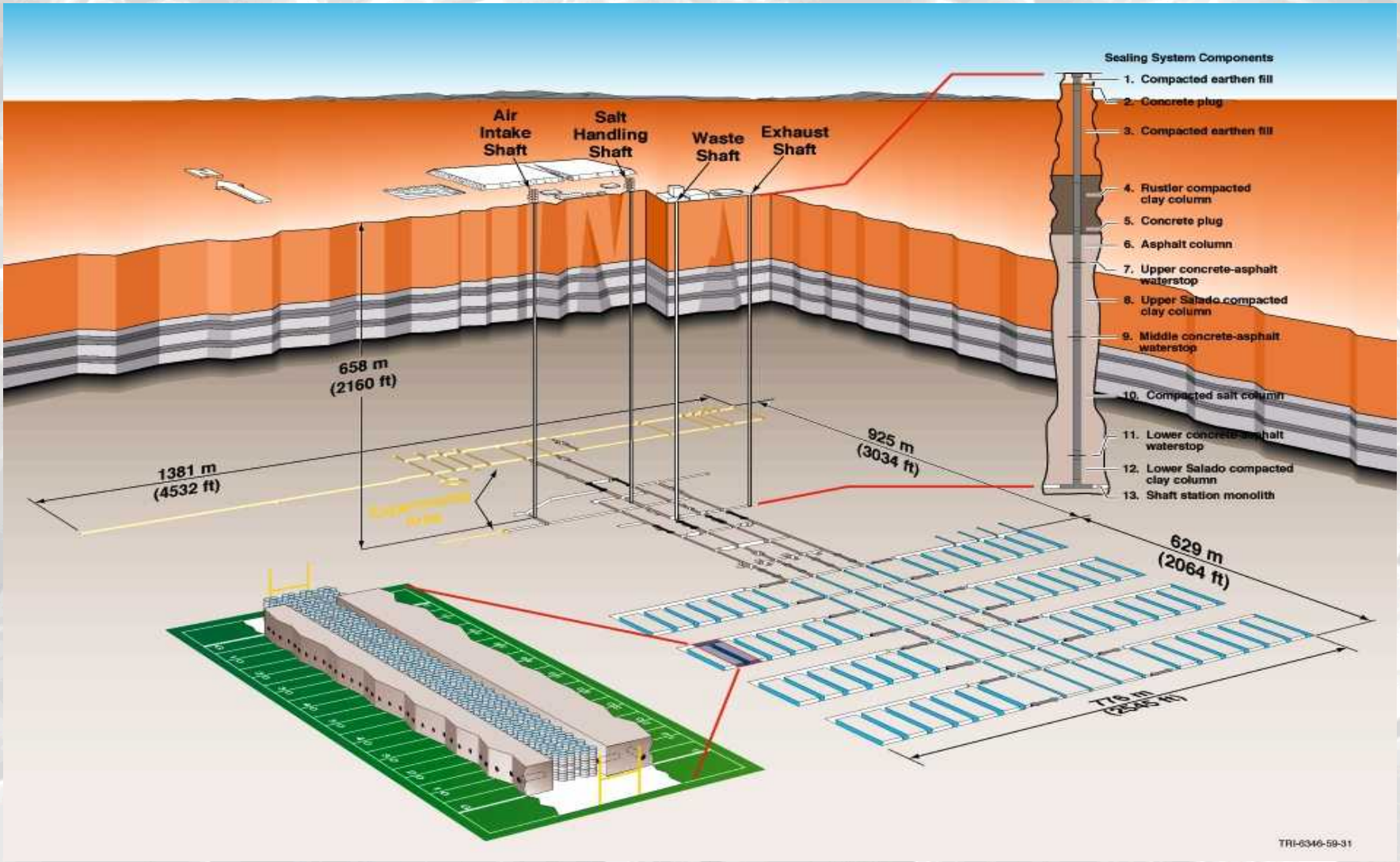
"The great advantage is that no water can pass through salt. Fractures are self healing…."

National Academy of Sciences, 1957

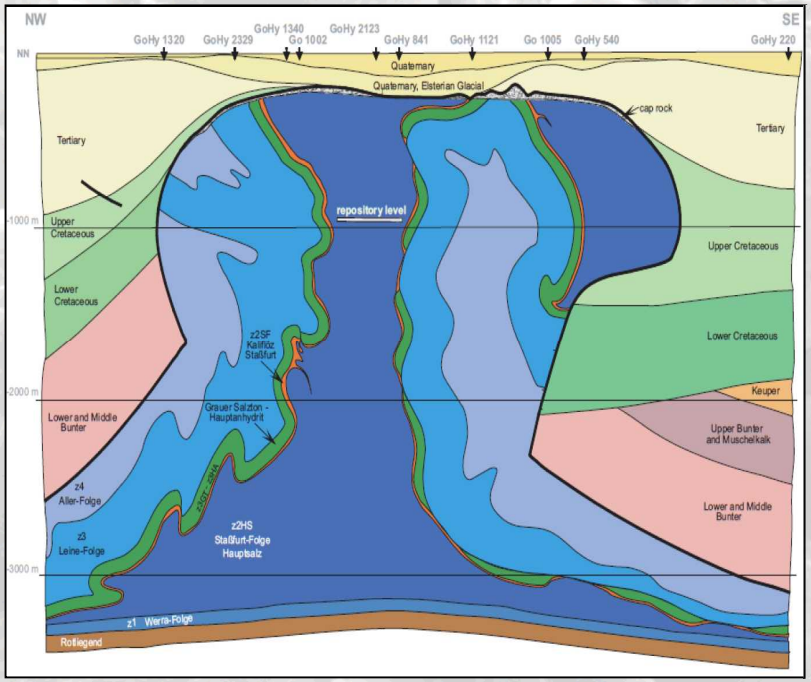
"No technical containments are needed – the natural barrier alone makes disposal in salt permanent"

ARMA Conference

WIPP Underground Layout



Geomechanical Evaluations of Gorleben

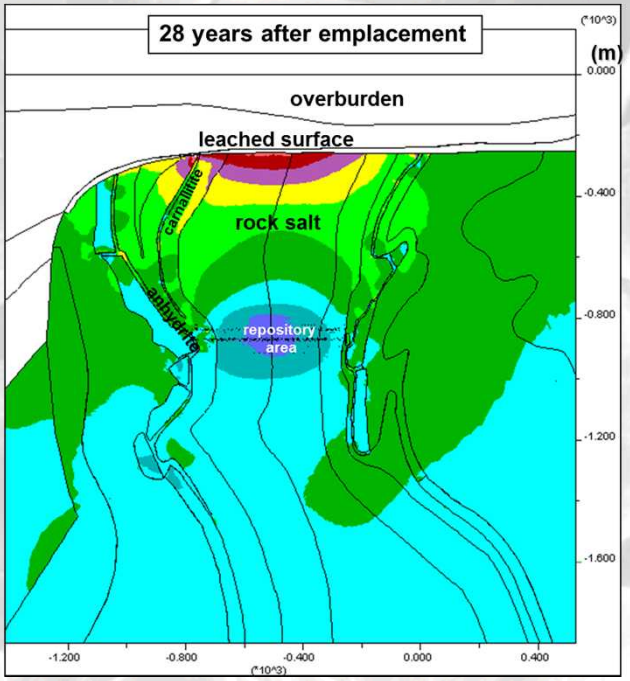


minimum stress criterion
factor of safety

$$n_F = \frac{\sigma_{MIN} + \sigma_{ZUG}}{p_{FL}}$$

violated
criterion
fullfilled

0.25
0.50
0.75
1
1.25
1.50
1.75
2.00



Preliminary safety analysis of the Gorleben site (VSG)

(Vorläufige Sicherheitsanalyse Gorleben)

International Salt Collaborations

Sandia National Laboratories

- Operational safety
- Site selection and characterization
- Laboratory and field tests under projected repository conditions
- Development of credible conceptual and numerical models
- Time dependent creep closure
- Excavation-induced damage to the host rock
- Engineered barriers
- Waste form, backfill, and rock interactions
- Contaminant flow, transport, and retardation tests and models
- Sealing of shafts and disposal areas
- Compliance with regulatory requirements
- Stakeholder involvement, education, and participation
- Peer review
- Transportation, handling and storage
- Repository development design, construction, and maintenance

Safety Case Context

- What are the remaining geomechanics issues for a salt repository for heat-generating nuclear waste disposal?
- Pertains to development of a license application, rather than to exploration of the entire breadth of salt research
- The technical foundation supporting a licensed salt repository has been developing in the United States and Germany since the 1960s
- Ample scientific bases exist to develop a safety case in the event a salt site is identified and governing regulations promulgated
- Some remaining geomechanics issues pertain to application of advanced computational tools to the repository class of problems
- Research areas such as constitutive models and performance of geotechnical barriers have industry applications beyond repositories

5th US/German Workshop

- Operational Safety
- Geomechanics Issues
- Underground Research Laboratory
- Capturing Early Evolution of Salt Excavations
- Features, Events and Processes

http://energy.sandia.gov/energy/nuclear-energy/ne-workshops/usgerman-workshop-on-salt-repository-research-design-and-operation/

Proceedings of the 5th US/German Workshop on Salt Repository Research, Design, and Operation

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign
Francis D. Hansen, Christi Leigh
Sandia National Laboratories
Walter Steininger, Karlsruhe Institute of Technology/ Water Technology and Waste Management
Wilhelm Bollingerfehr and Thilo von Berlepsch, DBE TECHNOLOGY GmbH

January 30, 2015
FCRD-UFRD-2015-00514
SAND2015-0500R

Future Work Concerning Integrity Analyses

Andreas Hampel	Dr. Andreas Hampel, Wissenschaftlicher Berater, Mainz
Sandra Fahland, Jörg Hammer	BGR
Nina Müller-Hoeppe	DBE TECHNOLOGY GmbH
Klaus Wieczorek	GRS
Till Popp, Wolfgang Minkley	IfG Institut für Gebirgsmechanik GmbH Leipzig
Frank Hansen	Sandia National Laboratories
Joachim Stahlmann, Christian Missal	Technische Universität Braunschweig
Karl-Heinz Lux	TU Clausthal

Outcome of discussions during the 5th US-German Workshop

Santa Fe, New Mexico

September 2014

- **Geomechanical integrity analysis of the repository is a main topic of PA**
  - Geological barriers
  - Geotechnical barriers
- **The scientific level of system analysis is high, but reduction of uncertainities is necessary**

Minimum Stress Criterion

The minimum stress criterion is decisive for assessment of the integrity of the geologic barrier (far field) as well as for some aspects when assessing the effectiveness of geotechnical sealing systems.

Geological barrier integrity

THMC-processes:

- Different numerical approaches and tools are available

1. Verification of the models
2. Benchmarking

Functioning of the technical barriers

THMC-processes:

- poor understanding of the acting mechanisms

1. Lab and field tests
2. Numerical tools for analysis

Properties of Crushed Salt Part 1

SALT RECONSOLIDATION PRINCIPLES AND APPLICATIONS

FINAL

6/24/2014

Frank Hansen[1)], Till Popp[2)], Klaus Wieczorek[3)], Dieter Stührenberg[4)]

[1)]Sandia National Laboratories, Albuquerque New Mexico USA

[2)] Institute für Gebirgsmechanik (IfG), Leipzig, Germany

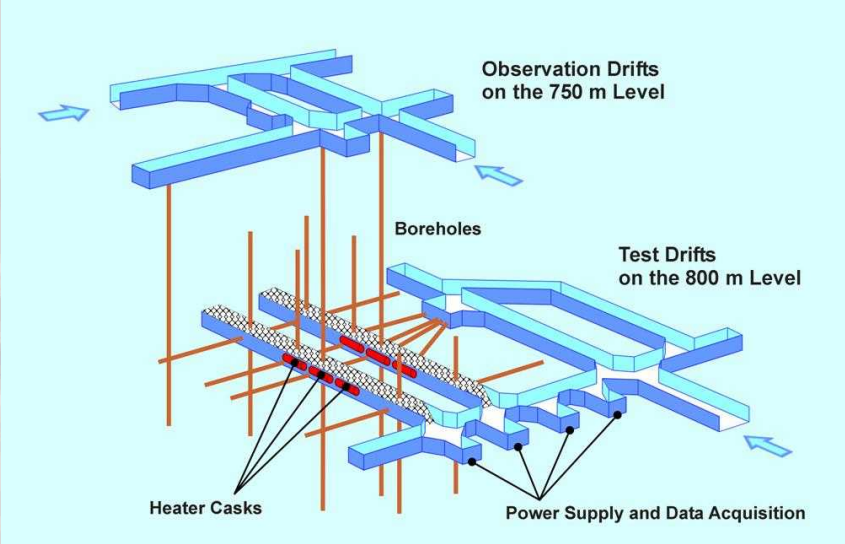
[3)]Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Braunschweig, Germany

[4)]Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, Germany

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the US Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2014-4502P.

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY



Properties of Crushed Salt Part 2

Sandia National Laboratories

Current knowledge provides confidence that granular salt will compact to a low porosity similar to natural salt formations, but this understanding has to be reliably demonstrated.

Key topics

- Analysis of natural analogues
- Development of constitutive laws

- Long-term compaction tests

- BAMBUS III – Revisitation after 15 years

Open tasks / key activities

➔ *Systematic selection and study of analogues*

➔ *Improvement, calibration and benchmarking of existing laws*

➔ BGR *develops a new experimental setup for long-term compaction test (up to 10y) on crushed salt*

➔ *In the framework of Asse site investigations: Characterisation of the crushed salt consolidation state*

in 2015 …

Mechanical Behavior of Salt

Sandia National Laboratories

Long-term behavior

Boundary conditions:

Forecast period:	10^3 < time (years) < 10^6
Deformation:	$0.1 < \varepsilon < 1$
Temperature:	20°C - 200°C
Strain Rate:	$3 \cdot 10^{-14} < \varepsilon\ (1/s) < 3 \cdot 10^{-11}$

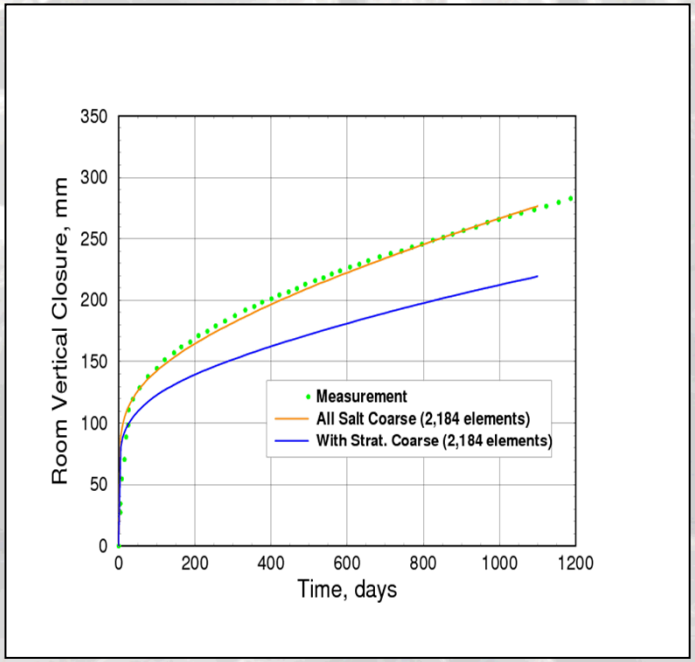
BMWi – Joint Project III: Comparison of current constitutive models salt

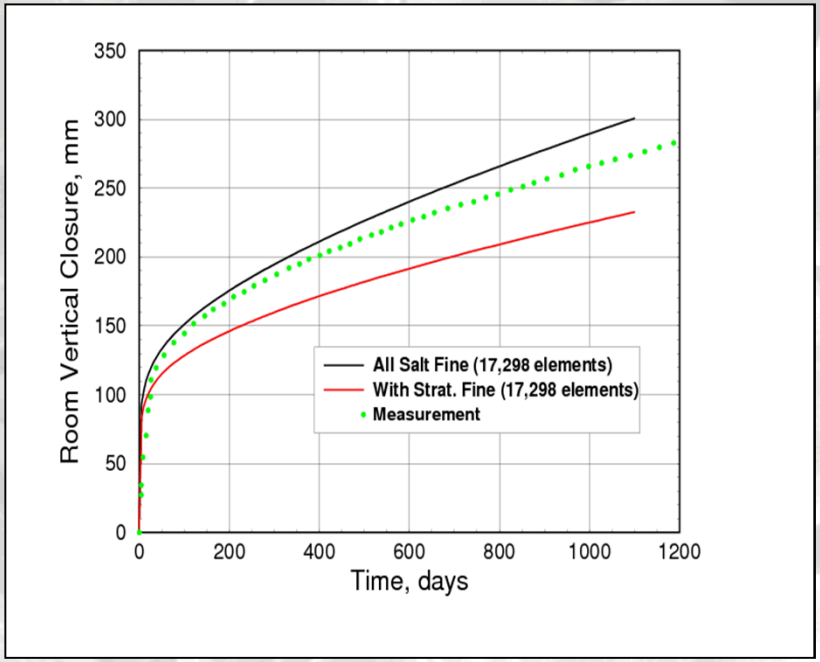
Ongoing research and cooperation since 2004 ….

Forthcoming key topics

- Healing at different P, T-conditions
- Discontinua mechanics, i.e. role of interfaces in salt
- Deformation behaviour at small deviatoric stresses
- Evaluation of the failure state under extensional conditions
- Assessment of the suitability of the existing constitutive laws

Benchmarking





Outlook of Certain Activities

(wish list)

- Compendium comparing bedded and domal salt for HLW repositories
- Future work concerning Mechanical Behavior of Rock Salt
- Joint Project III--the most productive and valuable collaboration at this time
- Collaborate on future field testing (if any)
- Joint publication on geotechnical seals
- Geomechanics of salt primer

Resources for Salt Repository R&D

- 2014 US/German workshop on Salt Repository Research, Design, and Operation

- http://energy.sandia.gov/energy/nuclear-energy/ne-workshops/usgerman-workshop-on-salt-repository-research-design-and-operationConstitutive model

- Finis -