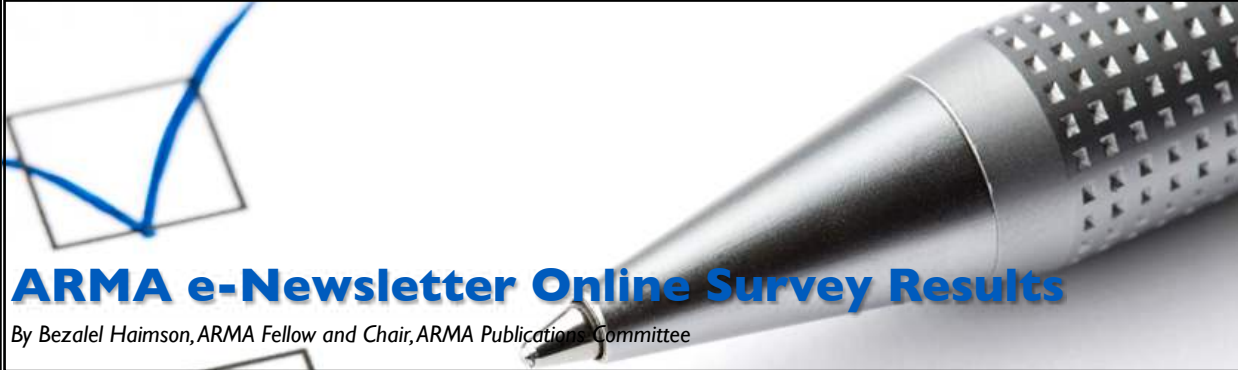


46th US Rock Mechanics/Geomechanics Symposium Chicago ♦ June 24 - 27, 2012

Volume 1, Issue 4, Fall, 2011

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By Bezalel Haimson, ARMA Fellow and Chair, ARMA Publications Committee

After publishing the first three issues of the ARMA e-Newsletter, the Publications Committee was looking for feedback:

Is this new initiative accepted by and useful to ARMA members?

To encourage readers to provide feedback, we decided to use a new internet tool, the online survey. The survey was conducted during the summer using SurveyMonkey.com, at no cost to us. Dr. Moo Lee, Sandia Labs and member of the Committee, facilitated the technical aspect of the survey. We asked ten questions, and 74 members responded. Here is a summary of the responses received:

- | | |
|---|-------------------------------------|
| 1. Have you read any of our e-newsletters published thus far? | Yes (82%) |
| 2. What percentage of the newsletter do you read in each of the three issues? | 25-100% (83%) |
| 3. Have you shared the e-newsletter with colleagues who are not ARMA members? | No (87%) |
| 4. What is your suggested ARMA e-Newsletter frequency of publication? | Quarterly (78%) |
| 5. Which of the major parts of the newsletter are you more interested in? | Technical Notes (86%) |
| 6. How would you rate the quality of the Technical Notes in the first three issues? | Good or Excellent (98%) |
| 7. How would you rate the quality of the newsletter design? | Attractive or Very attractive (84%) |

8. How can the e-Newsletter be improved to be more relevant to your research, career, and ARMA-related interests?

- "Publish more technical notes related to wellbore stability studies"
- "I believe ARMA does best when it bridges the civil, petroleum and geological engineering communities (one might add environmental to that mix) technologically"
- "Publish more technical notes, interviews with senior and well known scientists/engineers"
- "Shorter articles, please"
- "List rock mechanics papers in journals related to ARMA fields of technology"
- "Links to call for proposals; lecture series on fundamental rock mechanics courses"
- "Job announcements section needed"

9. Please suggest topics for Technical Notes to be included in the coming issues of the e-Newsletter:

- "Important developments and outstanding issues in hydraulic fracturing for oil and gas production"
- "Mechanics of rock failure during drilling"
- "In situ stress measurements"
- "Micro-mechanical modeling of fracture propagation"
- "Unconventional resources geomechanics"
- "Interviews with influential people on ARMA related topics"
- "Status of national / international projects in which rock mechanics plays an important role"
- "Risk Analysis in underground works"
- "CO2 sequestration and Large underground hydroelectric schemes"

10. Would you be interested in submitting a technical note on a subject of interest to you for publication in the newsletter? If YES, tell us what the subject would be and when you would have it ready for submission. Please respond directly to Bezalel Haimson (bhaimson@wisc.edu).

ARMA E-NEWSLETTER

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TECH Note

Deep Borehole Disposal of High-Level Radioactive Waste: An Alternative to Mined Geological Repositories

By Bill W. Arnold and Patrick V. Brady, Sandia National Laboratories

Background

Following the discontinuation of the Yucca Mountain Project, several alternatives are being investigated for the geological disposal of used nuclear fuel and high-level radioactive waste in the United States. Deep borehole disposal is one alternative to a mined geological repository that is being considered to address the unresolved problem of the United States' growing inventory of used fuel from commercial nuclear power plants and legacy wastes from the nation's defense programs. Although deep borehole disposal has been recognized as a potentially viable option for the disposal of such wastes for several decades, advances in drilling technologies have decreased the costs and increased the reliability of constructing boreholes of sufficient diameter to the required depths (on the order of 5 km).

The deep borehole disposal concept consists of drilling a borehole or array of boreholes with a bottom-hole diameter of 17 inches into crystalline basement rock in a geologically stable continental location, emplacing waste canisters containing used nuclear fuel or vitrified high-level radioactive waste from reprocessing in the lower 2,000 m of the borehole, and sealing the upper portion of the borehole. The disposal concept is shown schematically in Figure 1. Approximately 400 waste canisters containing a total of about 350 metric tons of used fuel rods would be placed in the disposal zone of a single borehole. The borehole seal system would consist of compacted bentonite seals, keyed-in cement seals, and cement plugs.

Several factors suggest that deep borehole disposal would be safe. The great depth of this disposal concept provides confidence in the isolation of these wastes from the surface and near-surface environment, relative to shallower mined geological repositories (examples shown in red in Figure 1). High groundwater salinity and generally low permeability of crystalline rocks at depths of several kilometers will ensure long residence times, low velocity of fluid flow, and limited interaction with shallower groundwater resources (typical lower limit indicated by the dashed blue line in Figure 1).

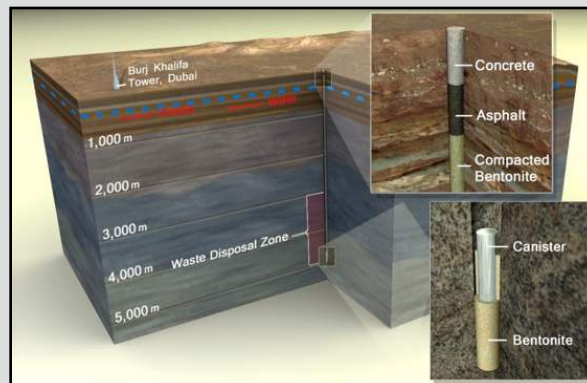


Figure 1. Concept for Deep Borehole Disposal of High-Level Radioactive Waste.

Salinity stratification prevents upward groundwater flow from deeper in the system (Park et al., *Advances in Water Resources*, **32**, 1352-1358, 2009). Geochemically reducing conditions in deep granite limit fuel corrosion and radionuclide solubility, while enhancing sorption and retardation of many radionuclides. Preliminary performance assessment calculations of the deep borehole disposal system indicate that these factors combine to limit potential future radiological doses to humans to about ten orders of magnitude below anticipated regulatory limits (Brady et al., *Deep Borehole Disposal of High-Level Radioactive Waste*, SAND2009-4401, Sandia National Laboratories, 2009).

- Continued on Page 3 -

ANNOUNCEMENTS

ISRM Rocha Medal 2013: Call for Nominations

Nominations for the Rocha Medal 2013 are being accepted by ISRM. The deadline for receiving nominations by the ISRM Secretariat is 31 December, 2011. The winner will be announced at the 2012 ISRM International Symposium in Stockholm, Sweden; that person will be invited to receive the award and deliver a lecture at the 2013 International Symposium.

The award, named to honor the memory of Past President Manuel Rocha, has been awarded by ISRM annually since 1982. Designed to stimulate young researchers, it is awarded for an outstanding doctoral thesis in rock mechanics or rock engineering. Besides the award of the Rocha Medal to the winner, one or two runner-up certificates may also be awarded.



The Indian National Group of ISRM announced that it will publish a twice-yearly journal and invites both readers and contributors. **The ISRM (India) Journal** aims to provide technical information and professional developments in the field of rock engineering worldwide. They would welcome research reports, review papers, and news of conferences, training programs, and important news. The editor and contact person is Uday Chander (uday@cbip.org). This news was submitted by V.K. Kanjlia, Member Secretary of the Indian Group of ISRM.

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TECH Note

Key Technical Issues

Several geological or hydrogeological conditions could compromise the safety of deep borehole disposal and would have to be avoided. The presence of economically attractive resources, such as potential ore deposits, petroleum reservoirs, or geothermal resources near the depths of the borehole disposal zone could attract future human intrusion. Overpressured fluids at depth, related to factors such as tectonic activity, active sedimentary basins, or geothermal heating, might cause upward flow and migration of radionuclides. Active volcanism, excessive seismicity, and strong differential horizontal stress could decrease the integrity of the borehole sealing system and waste isolation. Even when these factors are taken into account there is an abundance of potential real estate across the country that may be suitable.

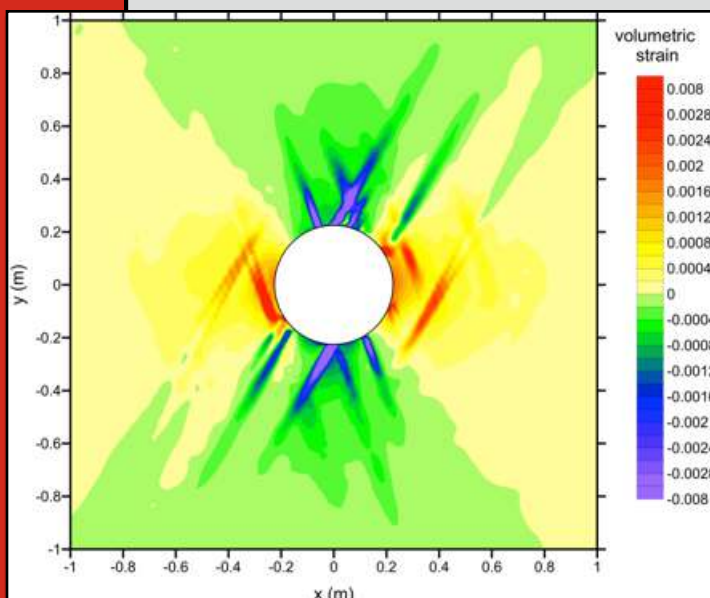
Seals performance is particularly important because the most plausible radionuclide release route is up the borehole shaft during the period when the waste is hot and there is a thermal driving force (roughly 1000 years). Designing and emplacing seals that are long-lasting is therefore a key to isolating radionuclides in deep boreholes. Emplacing chemically reactive seals that specifically sorb dose-critical radionuclides such as ^{129}I is one way to enhance borehole performance. ^{129}I is one of the few radionuclides in nuclear waste that remains soluble and poorly retarded under borehole conditions.

Coupled thermal-hydrologic processes driven by the heat from radioactive decay in the waste could drive groundwater flow and radionuclide transport. Thermal expansion of fluids within the borehole or disturbed rock zone surrounding it could move water through preferential pathways for relatively short periods of time. Free convection of groundwater could drive flow on larger scales for more extended times. Modeling has been used to incorporate these flow rates in performance assessment calculations and indicate that expected impacts to risk are negligible.

Coupled thermal-mechanical-hydrologic processes may have significant impacts on the permeability and flow in the host rock near the borehole, particularly under conditions of differential horizontal stress at these depths. The disturbed rock zone near the borehole provides a potential preferential flow pathway that could bypass borehole seals. Modeling of stress relief around the borehole at a depth of 4 km and anisotropic horizontal stress in simulated heterogeneous, fractured granite indicates significant volumetric strain in a complex pattern, as shown in Figure 2. Coupling with the thermal output in the waste disposal zone imposes additional compressive strain near the borehole during the period of peak temperatures that occur within about 10 years following waste emplacement.

Outlook for Deep Borehole Disposal

Deep borehole disposal of high-level radioactive waste has several advantages over a centralized mined repository, including high confidence in permanent isolation of wastes and potentially lower costs. This disposal concept can also be implemented in a modular fashion, reducing up-front deployment costs, potentially addressing issues of regional equity, and being attractive to countries with small radioactive waste management programs.



Left: Figure 2. Simulated Volumetric Strain for Anisotropic Horizontal Stress in Fractured Heterogeneous Granite Near a Borehole.

Because deep borehole disposal has not been investigated as well as mined geological repositories, the draft report from the presidential Blue Ribbon Commission on America's Nuclear Future (www.brc.gov) calls for "further research, development, and demonstration (RD&D)" of borehole disposal. Significant uncertainties remain about the key technical issues described above, as well as the effectiveness and durability of borehole seals, and are critical subjects of additional RD&D. In addition, a pilot deep borehole program could provide additional scientific insights, confidence in safety assessments, opportunities to evaluate engineering viability, and experience in relevant field testing within deep boreholes.

Acknowledgement

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.

**46th US Rock Mechanics/Geomechanics Symposium
Chicago ♦ June 24 - 27, 2012**

ARMA News

San Francisco Symposium: Exceeding Expectations

When you organize a conference or symposium, you have to wonder how it will turn out. Such events require considerable planning and effort. Conveners work hard to pick the right venue, solicit help organizing technical sessions, establish relevant field trips, invite prominent speakers, and manage all the other tasks that help to make a technical meeting worthwhile. But you really never know if these efforts were appropriate until the meeting occurs. Therefore, we were pleased -- and with a great deal of pride and some relief -- that the 45th U.S. Rock Mechanics / Geomechanics Symposium was a success.

This success is evidenced by the following. There were over 500 attendees, with representatives from 37 countries. Over 300 papers were published in the Proceedings and almost 280 podium or poster presentations were delivered. These results were all or nearly all record-setting.

There are a number of reasons for this success. First, the rock mechanics / geomechanics discipline is of vital importance in today's complex world. Perhaps the highest praise can be directed at the quality of podium speakers and poster presentations. We know how important this is to attendees and that it might possibly be the most important reason why we attend ARMA symposia.

Issues discussed spanned petroleum, mining and civil works. Topics ranged from developing huge underground openings at great depths to enhanced hydraulic fracture propagation in unconventional reservoirs. Many interesting topics were discussed, all of which define the fabric of our profession. The topics for plenary sessions demonstrate this:

- Priscilla Nelson talked about the use of underground urban spaces as an underutilized resource for storage, waste disposal, and infrastructure.
- Mark Zoback outlined some of the risks found with large scale carbon sequestration and compared those with the use of unconventional natural gas from shale deposits.
- David Singleton related his personal experience in drilling rescue borings for trapped Chilean miners.
- Keith Heasley spoke to the fact that recent mining disasters would require better analysis of the causes and the approaches to rescue for those events.
- George Guthrie gave an overview of the need for predictive and analytical tools for large scale CO₂ capture and storage.

Second, we can't downplay the importance of this year's setting. San Francisco is a city that most everyone loves to visit. Third, success was a result of the quality and quantity of volunteers who freely gave of their time to help organize this year's Symposium. Many people did so much to organize over 40 technical sessions, five plenary presentations, and 12 invited speakers. Banquet addresses were given by Xia-Ting Feng, President (incoming) of the International Society of Rock Mechanics and by ARMA's president, Mark Zoback. In addition, session developers and manuscript reviewers volunteered to read and comment on every paper -- maintaining ARMA's standard for quality.

On behalf of the organizing committee, we want to thank all those who attended the San Francisco Symposium, as well as all those who volunteered to help organize and conduct this event. It has been a pleasure to meet and work with such a diverse and interesting group of people.

Members of the Organizing Committee
45th U.S. Rock Mechanics / Geomechanics Symposium

Anthony Iannacchione, Chair
Gabriel Esterhuizen
Teri Nichols

Gangerico Ramos
Azra Tutuncu
Peter Smeallie

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ARMA News

San Francisco Symposium: Afghani Delegation

One of the outstanding features of the San Francisco Symposium was attendance by rock mechanics professionals and academics representing Afghanistan. The delegation attended as guests of ARMA. The delegation's attendance resulted from an October 2010 visit to Kabul by A. Wahab Khair, Professor Emeritus, West Virginia University and Don Banks, Geotechnical Consultant. Following that visit, ARMA received a grant from the National Science Foundation, with a primary objective to foster partnerships between Kabul University, Kabul Polytechnic University and US research universities. Attendance at the Symposium afforded the Afghani professors an opportunity to meet with engineers and scientists from academia, as well as private and governmental organizations, as a start in developing new contacts.

One of the Symposium sessions – entitled “The Status of Rock Mechanics in Afghanistan: Needs and Challenges” – was entirely devoted to papers prepared by members of the Afghani delegation. The papers described the Afghanistan geologic setting, prospects for oil/gas and mineral exploration, and an overview of transportation facilities. In the panel discussion that followed, delegation members emphasized the need for university facilities, equipment and classrooms to be able to produce the trained body of engineers and technicians necessary to meet the technical challenges presently facing Afghanistan. The discussion also emphasized the need for involvement by foreign companies and organizations, as partners, to help bridge the technological gap that exists today.

Members of the Afghani delegation expressed their appreciation to ARMA for the opportunity to meet scholars and professionals at the Symposium from both the United States and around the world. They issued an invitation to attend the Third Hindu Kush Geoscience Conference to be held on the campus of Kabul University, September 20-23, 2011. The theme of the conference will be Geosciences and Environmental Issues in Afghanistan and South-Central Asia. (Inquires can be made to James Springer at sprngr_jms@yahoo.com).

ARMA Awards

Each year at the annual symposium, ARMA members are recognized for outstanding contributions and careers in the profession of rock mechanics and rock engineering that are of benefit to the United States rock mechanics community. The ARMA Awards program is meant to:

- encourage teaching, research, and advancement of knowledge in rock mechanics;
- encourage collaboration and exchange of ideas and information between rock mechanics practitioners;
- promote high standards of professional practice among rock engineers so that civil, mining, and petroleum works might be safer, more economical, and less disruptive to the environment.

This year, the following were selected to receive ARMA Awards:

2011 Rock Mechanics Research Award: *Investigation of CO₂ Injection Induced Coal-Gas Interactions*, Zhongwei Chen, Jishan Liu, Derek Elsworth, Luke Connell, Zhejun Pan. Presented at the 43rd US Rock Mechanics Symposium; Asheville, June 2009.

2011 Applied Rock Mechanics Research Award: *A New Method to Estimate Paleoseismic PGA Using Dynamic Numerical Back-Analysis of Keystone Displacements in Historic Masonry Structures*, Y.H. Hatzor, R. Kamai, G. Yagoda-Biran. Presented at the 42nd US Rock Mechanics Symposium; San Francisco; June 2008.

2011 Case History Award: *Monitoring Steam Injection Deformation Using Microseismicity and Tiltmeters*, S.C. Maxwell, J. Du, and J. Shemeta. Presented at the 42nd US Rock Mechanics Symposium; San Francisco; June 2008.

2011 Dr. N.G.W. Cook Ph.D. Dissertation Award: *Strength of Transversely Isotropic Rocks*, Jianyong Pei, Doctor of Philosophy (Civil and Environmental Engineering), Massachusetts Institute of Technology – 2008, Thesis Supervisors: H.H. Einstein and A. Whittle.

DEADLINE ALERT:

Nominations for 2012: ARMA members are encouraged to identify and submit nominations for the 2012 ARMA Awards. Criteria and submittal details can be found on the ARMA Website: www.armorocks.org. The deadline for the 2012 ARMA Awards is 20 January 2012.

46th US Rock Mechanics/Geomechanics Symposium



Chicago • 2012 • June 24-27

We invite you to visit Chicago in June 2012, one of the great cities of the world, and participate in a program that focuses on new and exciting advances in rock and geomechanics. This symposium encompasses all aspects of rocks mechanics, rock engineering and geomechanics. **For additional information on the symposium, registration, accommodations and sponsorship:** www.arnasymposium.org

Conference Dates: June 24-27, 2012

Location: Westin Hotel – Michigan Avenue, Chicago, Illinois

Abstract Deadline: November 1, 2011

Author Notification: December 15, 2011

Paper Submittal: February 15, 2012

We invite scientific & engineering papers in:

- Carbon sequestration
- Coal Mining
- Compaction/subsidence
- Enhanced geothermal systems
- Fracture mechanics
- Hard rock mining
- Novel laboratory/field testing
- Rock mass characterization
- Rock physics and geophysics
- Scaling: length and/or time
- Slope stability, foundations, dams
- Surface/open-pit mining
- Characterization of stress, pore pressure, formation properties
- Coupled processes / chemo-poro-thermo-mechanical
- Numerical/analytical/constitutive modeling
- Drilling/wellbore stability/sand production
- In-situ stress measurements/modeling
- Hydraulic fracturing and monitoring
- Stability/support of underground openings
- Unconventional reservoirs (shale gas, oil shale, coal bed methane, hydrates)



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Marisela Sanchez-Nagel, Itasca Houston
Peter Smeallie, ARMA
Azra Tutuncu, Colorado School of Mines
Erik Westman, Virginia Tech

Professional Development Hours (PDH) are available for the Symposium. There will be technical tours, workshops and social activities. Please see the symposium website.