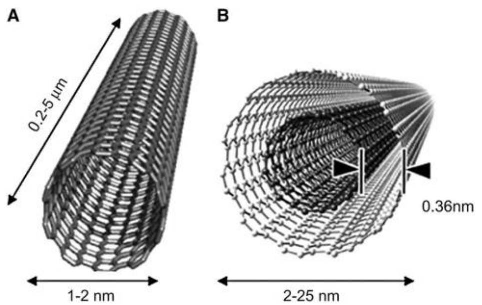
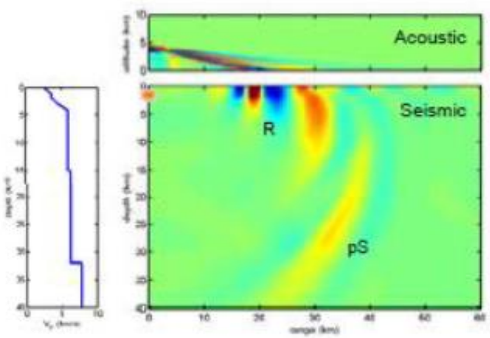
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

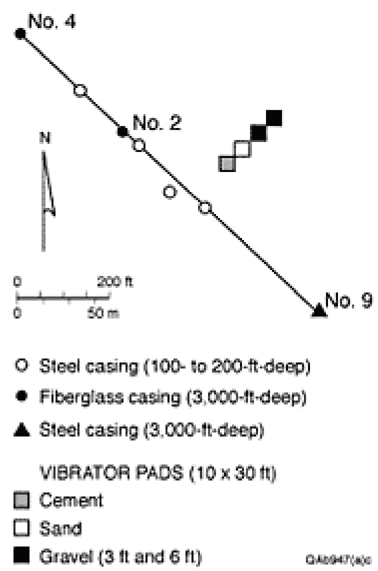
Multi-walled Carbon Nanotubes

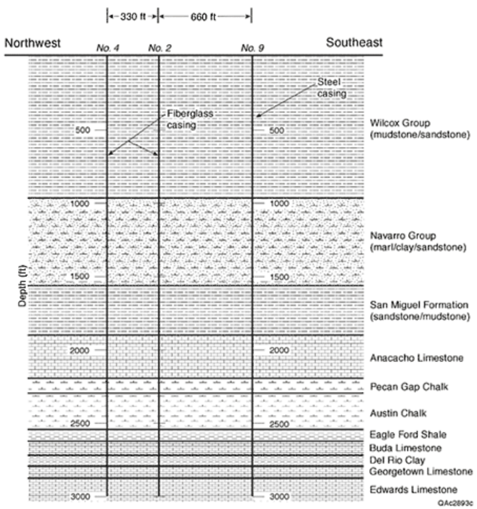


Forward Acoustic Modeling



UT Devine Site





Advanced Downhole Acoustic Sensing for Wellbore Integrity

Project Officer: Alexandra Prisjatschew

Total Project Funding: $3.8M

November 14, 2017

Principal Investigator

Thomas Dewers

Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

Advanced Downhole Acoustic Sensing for Wellbore Integrity

Project Objectives

Develop step-change in *non-destructive*, *non-intrusive*, *continuous monitoring* of wellbore integrity including:

- Downhole networks for continuous acoustic sensing at relevant frequencies
- Cable-free sensors and/or acoustic contrasting agents emplaced in cement for behind-casing monitoring to improve signal-noise ratios and flaw detection
- A means to excite sensors or contrast agents continuously, or at will
- Enhanced methods for data acquisition, filtering signals, and machine-learning for detection in complex, noisy, high-temperature-high-pressure (HPHT) downhole systems.

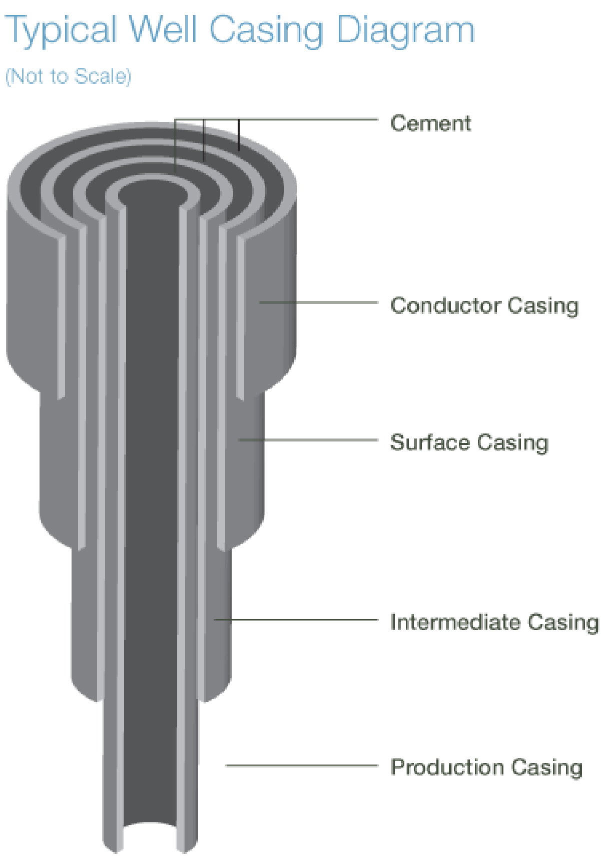
Problem Statement

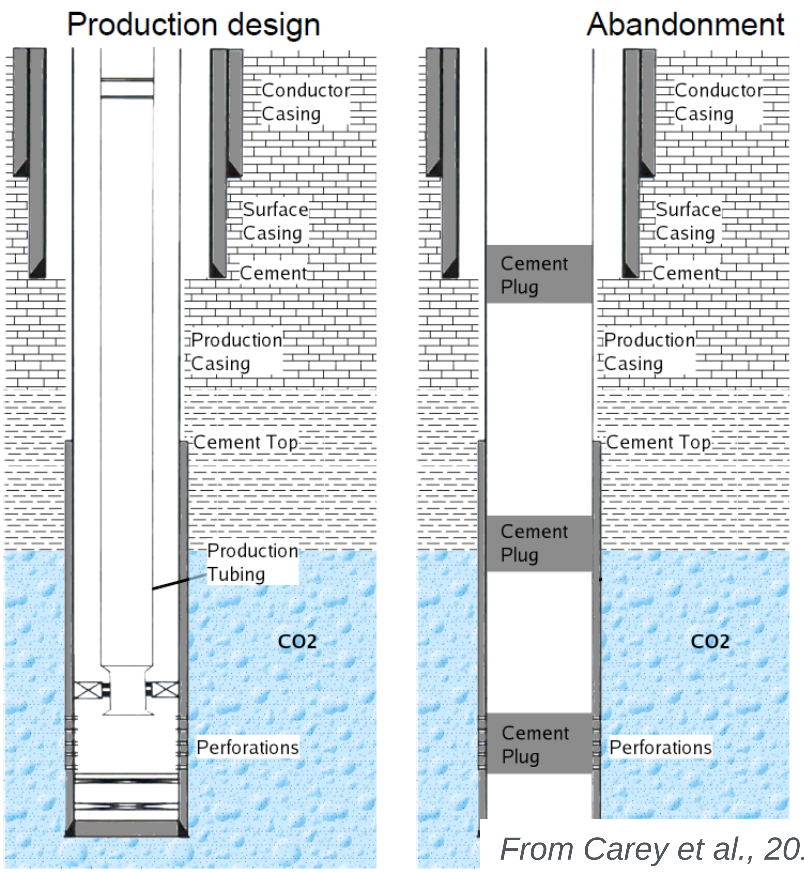
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

"Wellbore integrity refers to… zonal isolation of liquids and gases from …the target formation or from intermediary layers through which [a wellbore] passes"

Jackson, PNAS, 2014

"Application of technical, operational, and organizational solutions to reduce risk of uncontrolled release…throughout life cycle of a well" *NORSOK, 2014*





From Carey et al., 2010

Personnel

Sandia National Laboratories (SNL): Thomas Dewers (testing at conditions, acoustics), Ed Matteo (cement science), Leiph Preston (forward finite difference modeling); Zack Cashion (sensor development and deployment); Budi Gunawan (fiber sensing and deployment).

Los Alamos National Laboratory: Bill Carey (cement-CO_2 interaction, testing at conditions), Paul Johnson, advanced wave physics)

Purdue: Laura Pyrak-Nolte (physics and interpretation of guided and body waves in layered media, machine learning, failure mode detection)

UT-BEG: David Chapman (sensor development), Praveen Pasupathy (PAT design, sensor miniaturization, fabrication, ruggedizing) and Mohsen Ahmadian (contrast agents, CA, and CA/sensor/tool deployment/testing at Devine)

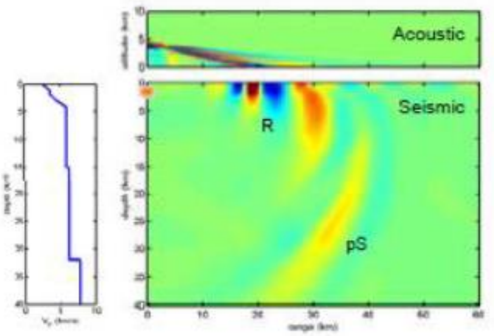
UNM: Shreya Vemuganti (PhD student), Mahmoud Taha and John Stormont (cement fabrication and design, functionalized carbon nanotubes)

Methods/Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

***Goal 1**: For the proposed research, we will focus on guided wave excitation and detection, using higher frequency excitation and detection with techniques recently developed by Pyrak-Nolte at Purdue and Paul Johnson at LANL. Excitation will be accomplished by either or both of the contrasting agents or passive acoustic tags described below. Advanced forward acoustic modeling will be performed at SNL, which will guide the choice of, and subsequent development, of the sensing agents.*

- Guided ultrasonic waves (Pyrak-Nolte et al., 1996; Shao et al., 2015) are a relatively new area in non-destructive testing
- Capable of propagating along interfaces or between surfaces for distances on the order of 25 – 50 wavelengths
- Sensitive to the bonding condition of the interfaces/surfaces

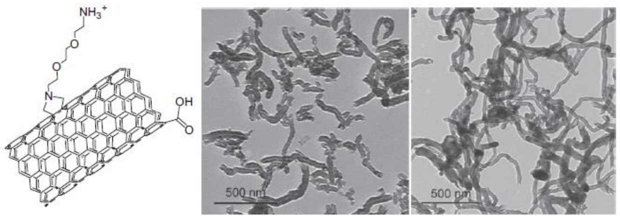


Methods/Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

__Goal 2__: For the proposed research, using HPHT rock mechanics and acoustic facilities at SNL and LANL, we will test behavior of single-walled carbon nanotubes as cement contrast agents under downhole conditions. We will also consider new proposed contrast agent additive by the UT-BEG. These will be used considered either individually or in combination to enhance PAT functionality.

- Used to improve acoustic imaging to increase detection depth and to improve signal-to-noise ratio
- Functionalized multi-walled carbon nanotubes
- Consideration of other acoustic contrast agent additives.



MWCNTs, from Delgou et al., PNAS 109(41), 2012

__Goal 3__: For the proposed research, the BEG will apply expertise in modifying off-the-shelf piezoelectric and/or acoustic materials as contrast agents or PATs for cement embedment. SNL will collaborate in miniaturization and ruggedizing of PATs for downhole use.

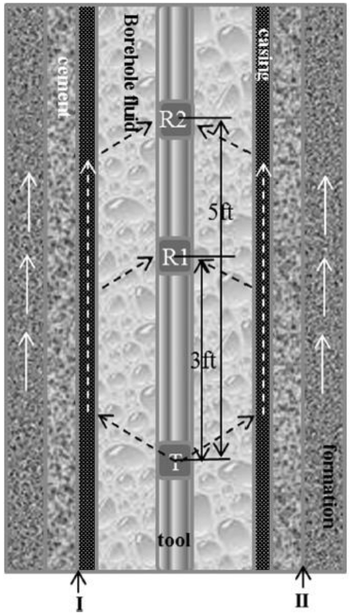
- Cable-free sensors for embedding in cement that are excited acoustically to send or receive information acoustically
- Passive i.e. operate with no onboard battery or electronics

Methods/Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Goal 4: *For the proposed research, SNL and LANL will collaborate with the BEG to investigate limitations of using passive frequency sources and downhole casing ultrasonic excitation as viable and continuous sources of embedded sensor excitation. These will be accomplished first in bench-top laboratory testing, but will advance to downhole proof-of-concept testing at the Devine site.*

- Cement bond log and/or variable density logging (CBL/VDL) wireline tools as is current practice, but this would restrict sensor excitation and detection to usual cement bond logging or to potentially dangerous work-over periods.
- Passive acoustic sources, such as injected or produced fluid in the borehole tubing itself (e.g. during active injection of $scCO_2$, brine withdrawal, or circulation of geothermal heat-exchanging fluid).
- Use of the casing itself (which could be excited ultrasonically at the surface or downhole via specially designed couplers).

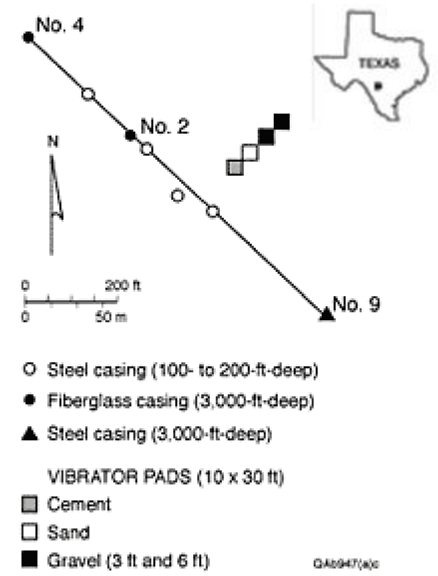


CBL/VBL, Wang et al., 2017, JASA

Methods/Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Goal 5: *For the proposed research, BEG together with SNL will examine use of downhole fiber DAS in detecting signals of activated CA and PAT in micro-annuli detection. This will be done first at SNL under laboratory HPHT conditions, with a Micron Optics optical sensing interrogator, then tested under downhole conditions at Devine.*



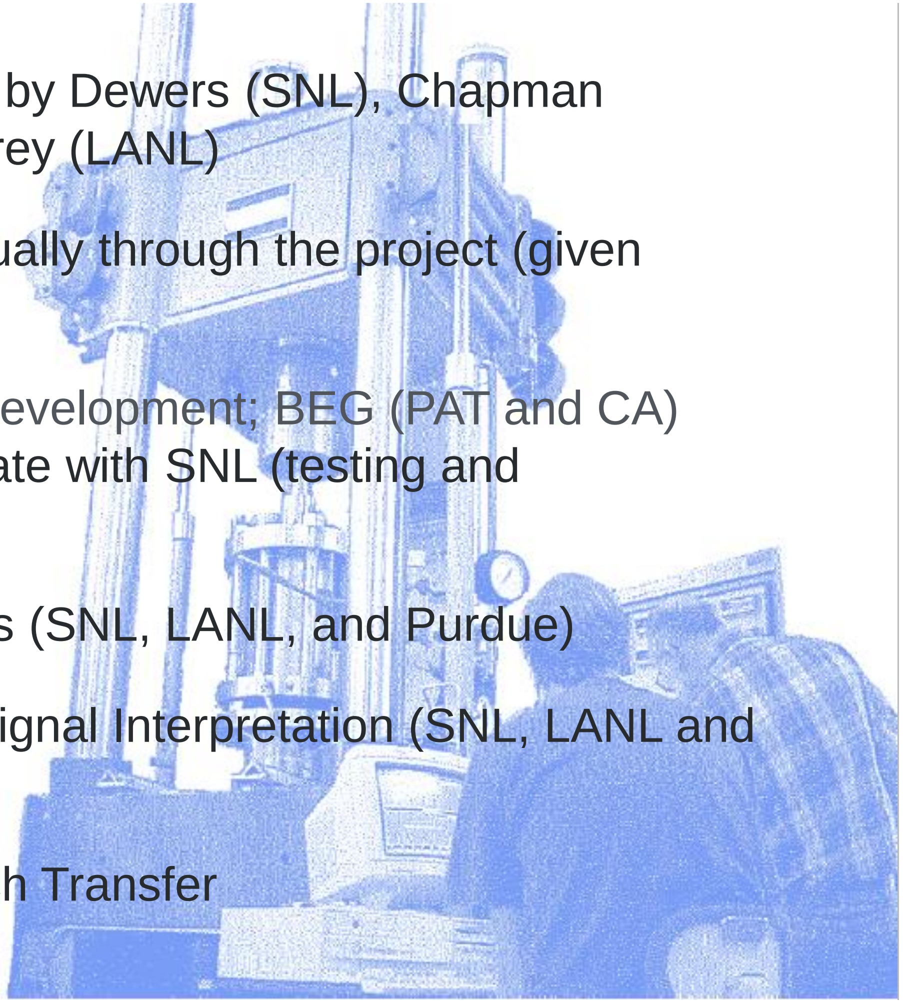
- Fiber optic DAS are being deployed in a variety of structural health and sensing configurations for wind turbine and ocean energy harvesting applications
- Cross well acoustic detection of fracture networks

Goal 6: *For the proposed research, Purdue and LANL will collaborate in advancing methods for detection using full waveform techniques. SNL and LANL will perform laboratory acoustic imaging of interfacial flaws in cement-casing mock-ups with acoustic imaging under HPHT conditions, including tests performed with in situ x-ray computed tomography, as "ground truthing" for the signal detection algorithms.*

- Detection of material-based CA and/or PAT through reconstruction,
- Inversion techniques deployed in acoustic (NDE/T) based on impedance (Z) changes
- Acoustic backscatter and acoustic 'tomographic' reconstruction also to be explored

Task Structure

- Task 1: Project Management, shared by Dewers (SNL), Chapman (BEG), Pyrak-Nolte (Purdue) and Carey (LANL)
- Task 2: Go/No-Go evaluation, bi-annually through the project (given below)
- Task 3: Sensor and Contrast Agent Development; BEG (PAT and CA) and UNM (CNT CAs) teams collaborate with SNL (testing and ruggedization)
- Task 4: Benchtop testing and Analysis (SNL, LANL, and Purdue)
- Task 5: Elastic Wave Modeling and Signal Interpretation (SNL, LANL and Purdue)
- Task 6: Field Implementation and Tech Transfer



Technical Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

(Simplified) Milestones and Schedule

FY	Milestone Title	Task	Description	Completion Date	Deliverable
18	Sensor 1	3	Sensor Selection Completion	Q2	Sensor Report I
18	Test 1	4	Phase 1 Testing	Q4	Testing Report I
18	Model 1	5	Modeling Sensors with Guided Waves	Q4	Modeling Report I
19	Sensor 2	3	PAT Development	Q2	Sensor Report II
19	Test 2	4	Phase 2: Cement Testing at Conditions	Q4	Testing Report II
19	Model 2	5	Wellbore Model	Q2	Modeling Report II
19	Well Update	6	Status Update	Q4	Well Report I
20	Sensor 3	3	CA/PAT Activation Update	Q2	Sensor Report III
20	Test 3	4	Cement Structure Impact	Q2	Testing Report III
20	Model 3	5	DAS Comparison	Q2	Modeling Report III
20	Well Mtng	6	Status of Well Testing	Q1	Devine Site Visit and Report
20	Final Report			Q4	Final Report

Go/No-Go Decision Points

1. **At the end of Q1 FY18**: Lab Testing and Modeling check viability of using CA and PAT technologies for use in high frequency micro-annuli and small crack detection. Characterization of Devine cores and rock lithology.

2. **End of FY 18**: If modeling and benchtop testing suggest downhole Fiber DAS sensing with CBL tool activation of PAT is feasible, then project is to continue.

3. **End of Q2 FY19**: Decision as to whether off-the shelf CA and/or piezoelectric materials perform satisfactorily, or further development is needed. Tool benchmarking at Devine in existing wells with cement defect and DAS/FO with no CA/PAT.

4. **End of FY19**: Validation of approach in Devine Field Studies and Sensor/CA in Lab Studies. Is continued well testing at Devine yielding satisfactory results? Are lab results translating to field setting satisfactorily? If so, then continue. Devine well construction with cement defect and with embedded CA/PAT?

5. **End of Q2 FY20**: Can sensors be activated sufficiently using passive noise or by sonication of casing? Can CA contrasts be detected with fiber arrays? Decision point as to viability of full approach for noninvasive well integrity monitoring.

Research Collaboration and Technology Transfer

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

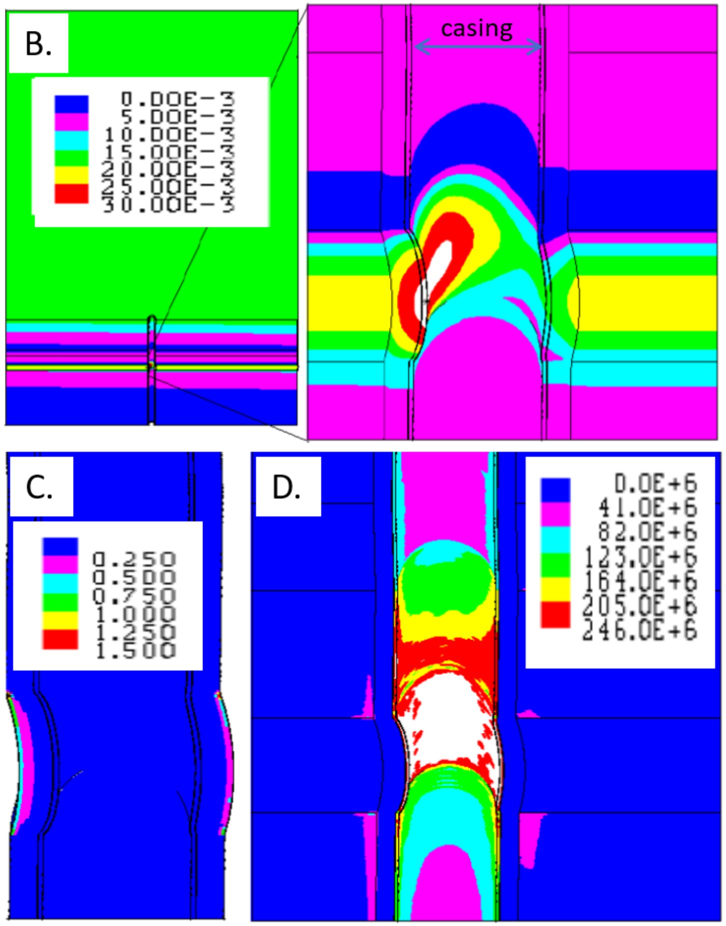
- Organized AGU Wellbore Panel Session on Wellbore Integrity with panel members from industry and academia (Dec 10, 2017)
- Discussions with Steve Nowaczewski from TransCanada
- Discussions with Yang Liu and David Linton Johnson from Schlumberger-Doll
- Discussions with Pioneer on sensor deployment
- UT-BEG co-PIs are part of the UT-Advanced Energy Consortium supported by industry http://www.beg.utexas.edu/aec/members.php

Summary

Together, these goals for the proposed research include:

- Feasibility assessment and development of noninvasive, continuous borehole cement evaluation methods
- Investigating acoustic contrast agents, embedded sensors (passive acoustic tags), methods for sensor excitation, and new methods of detection of damage from the associated signals

Wellbore integrity plays a crucial role in maintaining US energy and environmental security by enabling sustainable injectivity, resource recovery, and prevention of emergent failures



Numerical Models of Wellbore Failure, Dewers et al., in press)