Autonomous Monitoring of Wellbore Integrity Applying Time-Reverse Nonlinear-Elastic Wave Spectroscopy and Fiber Optic Sensing and Communication

Project Number (FWP-FE-853-17-FY17)

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TRIAD Property

Outline

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- Approach
- Impact
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- Accomplishments to date
- Lessons learned
- Synergy opportunities
- Project summary

Collaborators and Background

Team

Los Alamos National Lab (project lead)

- **P. Johnson (PI), C. Donahue (Co-Pi),** M. Remillieux, B. Carey, E. Dauson, L. Beardslee, L. Frash, S. Boyce, and E. Rougier
- Acoustics (nonlinearity, time reversal, signals from noise); machine learning; wellbore integrity; lab-scale experiments; project integration; DAS

Lawrence Berkeley National Lab

- **S. Nakagawa**
- Acoustics; fiber optics

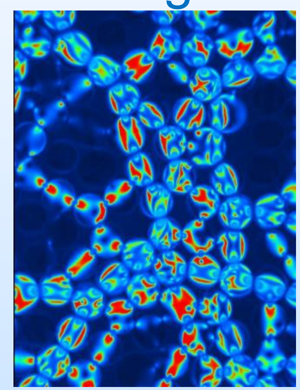
Clemson University

- **L. Murdoch**, L. Hua, H. Xiao, S. DeWolf
- Fiber optics, geomechanics, acoustics

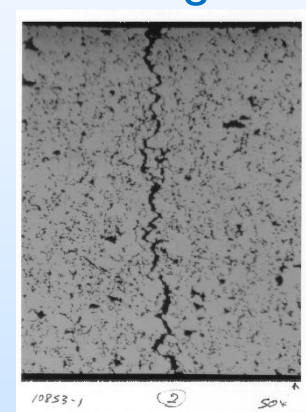
Chevron, ETC

- **H. Goodman**
- Field application needs

Distributed “damage”



“Localized damage”



Background to Approach

Our previous work has demonstrated:

- Nonlinear acoustical methods probe mechanical damage in complex earth materials;
- Acoustic time-reversal methods used to focus energy (including within earth materials);
- Machine-learning algorithms can extract small seismo-acoustic signatures from noisy backgrounds;
- Fiber optic sensors can be used to monitor strain at high resolution;
- Microwave photonics can measure distributed strain with optical fiber using non-proprietary methods.

Project Overview

Goals and Objectives

Goals and Objective: **Development of an autonomous system that can be deployed in wells for unattended long-term (e.g., decades) to monitor both wellbore integrity and stress changes near wellbore**

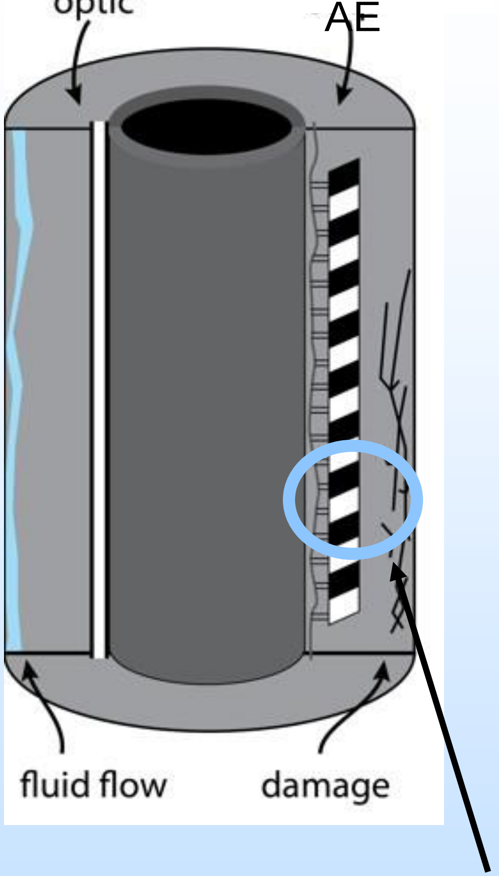
- Need: affordable, robust, autonomous system for monitoring wellbore integrity, especially post closure
- Need: detect leakage signatures for long term CO_2 monitoring

Innovation: Combination of:

(i) Fiber optic sensing to track near-borehole anomalous stress evolution associated with damage and to detect acoustic signals

(ii) Supervised machine learning to extract passive seismo-acoustic signals for long term monitoring of associated with leakage;

(iii) Active acoustics using embedded sensors and Time Reverse Nonlinear Elastic Wave Spectroscopy (TR-NEWS) to probe for localized damage



Approach

A. Listen for leakage in near-wellbore region using passive acoustic methods (specific objective 1; task 3)

i. Identify/discover signatures

ii. Evaluate ability of embedded acoustic sensors to detect signature(s)

iii. Develop machine-learning algorithms to extract signature(s) autonomously, including the extraction of signal from noise

B. Interogate and locate damage regions with *time-reversal nonlinear elastic wave spectroscopy* (TR-NEWS)

i. Demonstrate the ability to focus acoustic energy at specific points along a wellbore using time reversal (specific objective 2; task 4)

ii. Identify/discover nonlinear elastic signatures associated with damage zones and leakage pathways (specific objective 3; task 5)

C. Monitor strain/stress evolution in near-wellbore region using fiber optic sensing

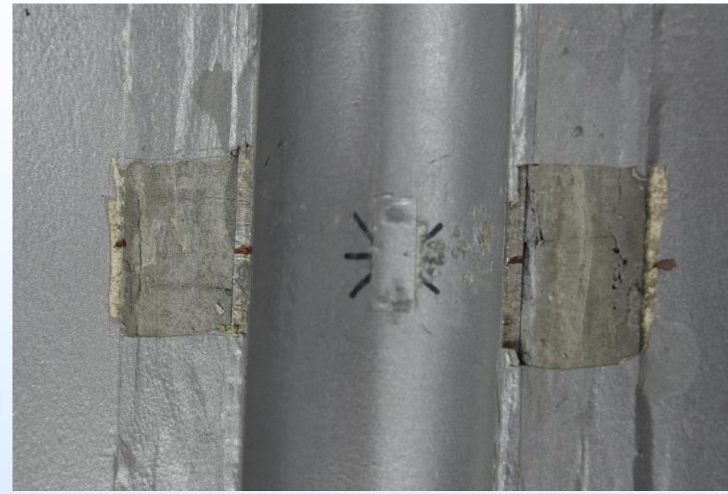
i. Demonstrate the ability of an embedded fiber optic cable to detect strain tied to loss of integrity in the near-wellbore region (specific objective 4; task 6)

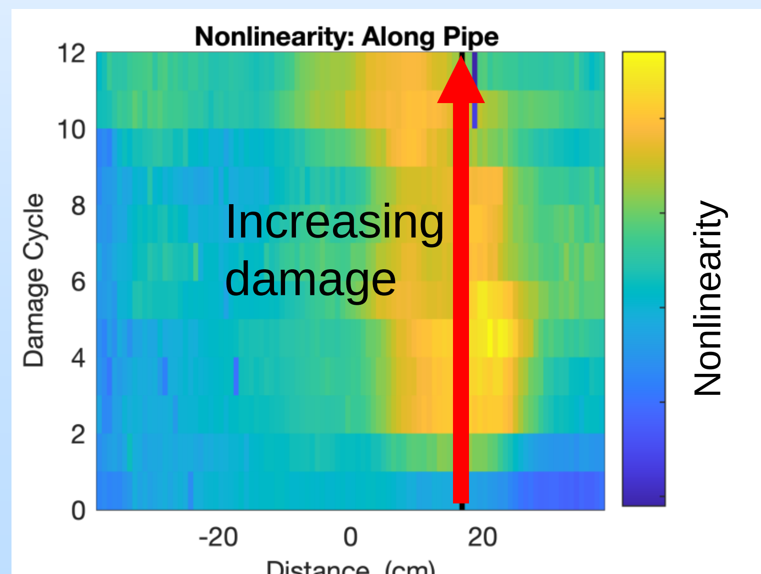
ii. Evaluate the feasibility of measuring distributed strain and acoustic spectra using non-proprietary fiber optic techniques

Half Pipe to Inspect and ground-truth Damage

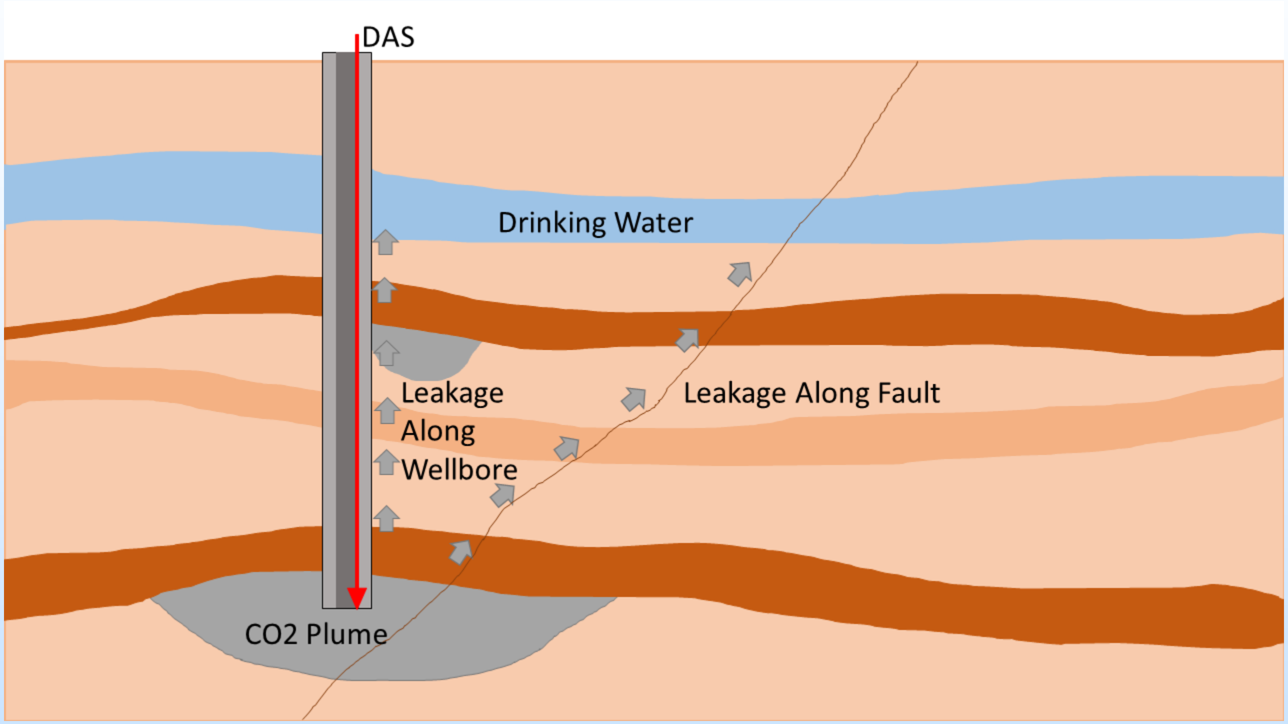
- Create local damage
- Use Time Reversal to look for local signs of nonlinearity

Half cased wellbore in 1 ton of Berea





iDAS



Product Specifications

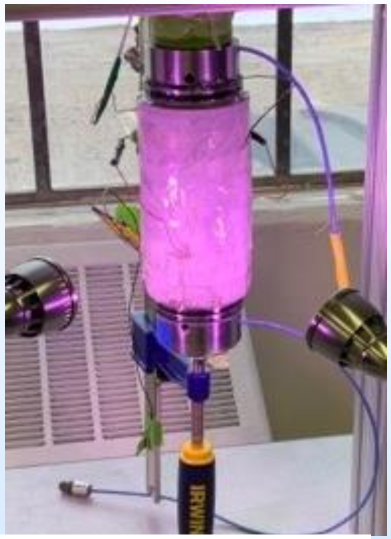
Sensing Capabilities

Range: 0 - 40km

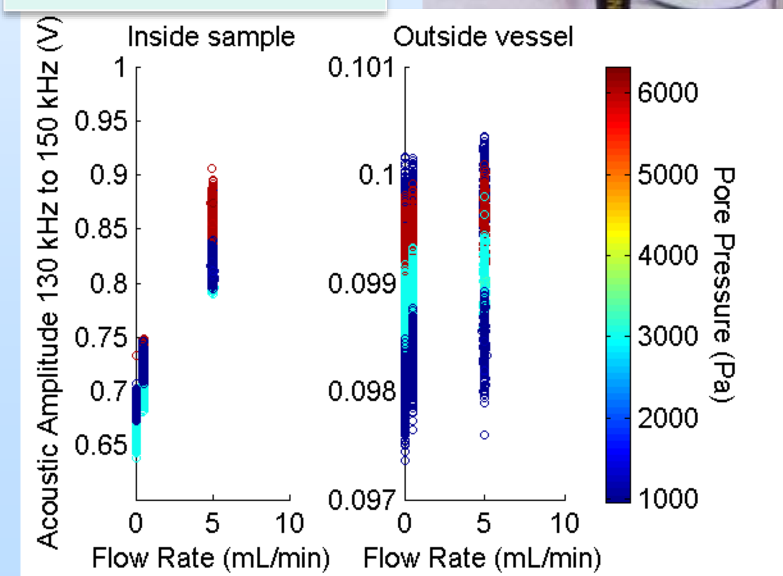
Frequency Range: 0.01Hz - 50kHz

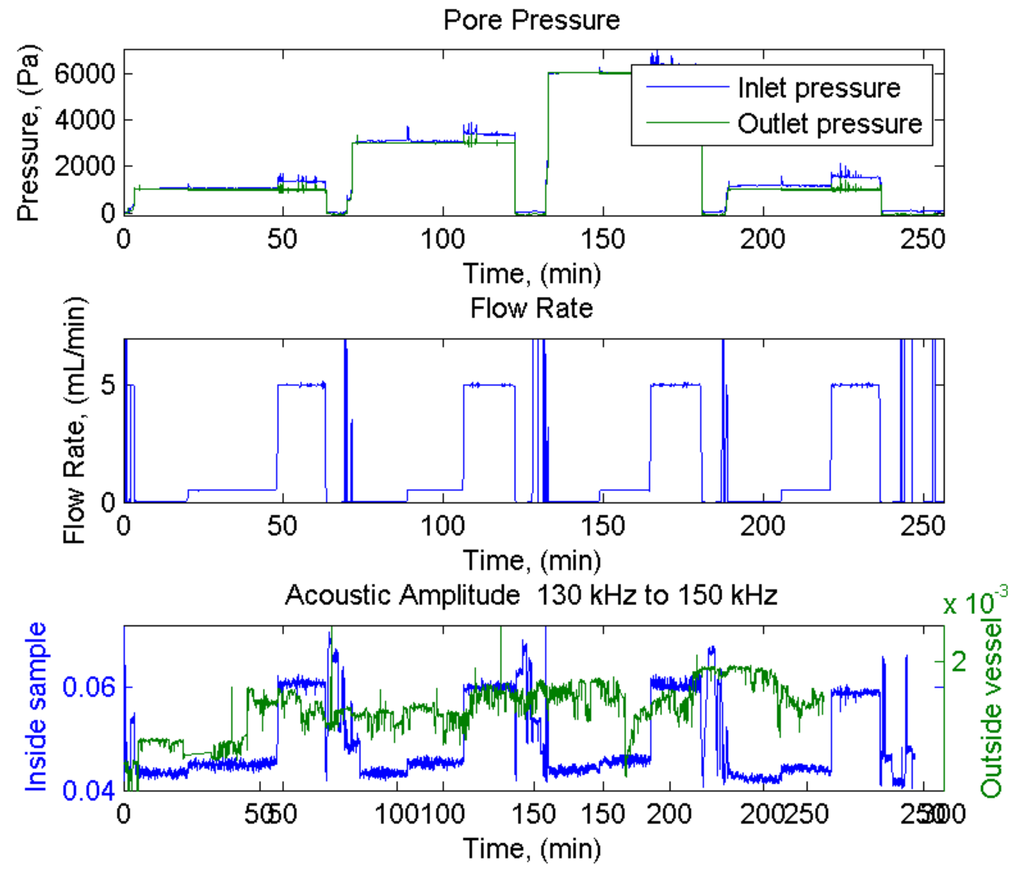
Spatial Resolution: down to 1m*

Monitoring Acoustic Signals

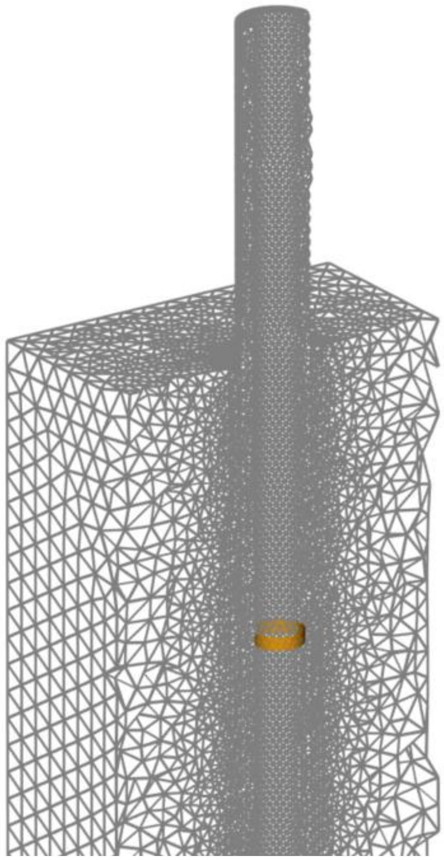


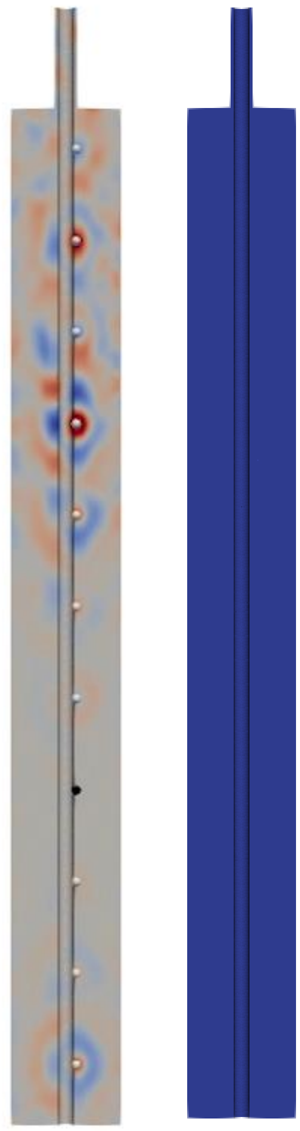
- Listen to flow through a cracked rock
- Use machine learning to look for signatures

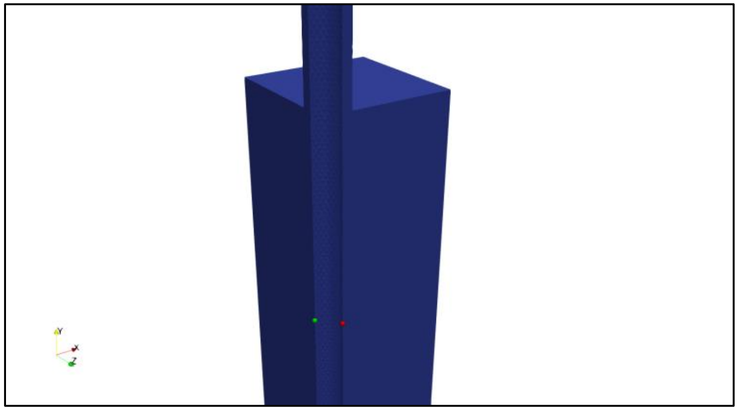


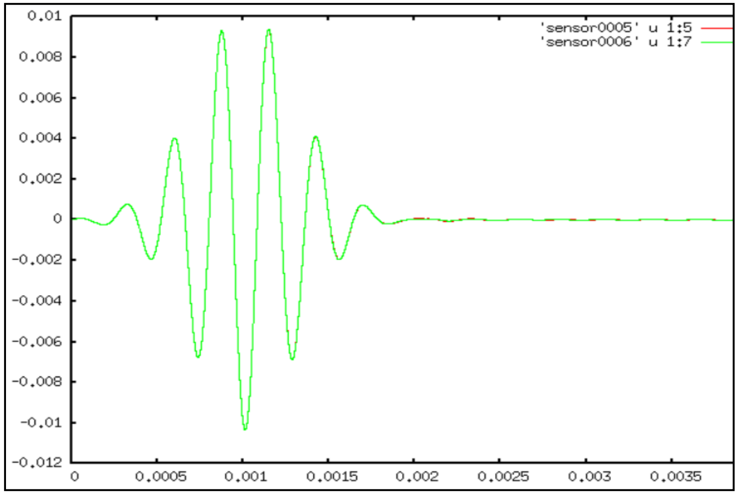


Time Reversal Simulations









Bending mode
Torsional mode
Longitudinal mode

Accomplishments to Date

- Performed TR in open hole and exposed cased half-pipe with laser vibrometer and fiber optics
- Simulated TR in open hole and cased hole
- Tested two optical fiber systems with TR on large sandstone block and in half-pipe
- Acquired iDAS system
- Gathered data and applying Machine Learning to acoustic signal generated by flow through a cracked rock in pressure vessel
- Simulation of TR-NEWS system show many sources are needed

Lessons Learned

- DAS shows promise
- Need sufficient reflectors and/or sources in open hole for time reversal
- Difficult to create damage for evaluation in case wellbore
- Anticipate pieces will be in place at end of project to move to prototype development

Synergy Opportunities

- **Leak Detection over large areas** – Youzuo Lin. Some signatures discovered and algorithms developed in this effort may be relevant to our project—lessons learned will be shared.
- **Monitoring Reservoir Displacements** – Paul Johnson. Particularly looking at the State of Stress.
- **Monitoring Seismicity** – Ting Chen
- **Ground Base Nuclear Explosion Monitoring** – Michael Begnaud. Interest in applying DAS
- **Global Security** – Emily Schulze-Fellenz. Interest in applying DAS.

Project Summary

Key Findings:

- TR NEWS computer simulations show the procedure in full
- The TR Experiments work reasonably in a laboratory borehole and will require optimization
- iDAS System has been delivered, developments in iDAS show a low cost method for leakage monitoring

Next Steps:

- Advance 'leak listening' studies applying machine learning. Laboratory and simulation.
- Planning field test using iDAS
- Continue simulations of listening and state of stress
- Publish tests of TR NEWS

Appendix

Benefit to the Program

- GOAL: development of autonomous system that can be deployed in wells for long-term (e.g., decades), unattended monitoring both wellbore integrity and associated stress changes (Topic Area 2).
- If successful in achieving the overarching R&D goal, the outcome would be a cost-effective option (hardware and software) for long-term autonomous monitoring of wells.
- This technology would have broad application in subsurface operations, where maintaining and monitoring wellbore integrity is central to reservoir management strategies (including geothermal operations, oil/gas operations, injection operations). However, the largest benefit to national subsurface energy interest likely lies in post-closure monitoring of wellbore integrity, as needed for CO2 storage operations. This system would be a cost-effective autonomous option to provide the data necessary to ensure that wellbore integrity is being maintained, targeting a central need in any CO2 storage.

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(ii) Active acoustics using embedded sensors and Time Reverse Nonlinear Elastic Wave Spectroscopy (TR-NEWS) to probe for localized damage

(iii) Fiber optic sensing to track near-borehole anomalous stress evolution associated with damage

Organization Chart

LANL: overall lead

LANL and LBL: TR NEWS simulation and experiment

LANL: DAS and Machine learning applied to leak signals, experiment and simulation

Clemson: consultation on Fiber Optics

Chevron: consultation on R and D, and application

Gantt Chart

(project initiated late Q1 FY18)

Table 1. Timeline for project by task and project year (PY), with two go/no-go (G/NG) decision points.

Task	Task Description	**PY1**					**PY2**					**PY3**				Product	Dependencies
		Q1	Q2	G/NG	Q3	Q4	Q5	Q6	G/NG	Q7	Q8	Q9	Q10	Q11	Q12		
1.0	Technical Project Management (200)															☐ Quarterly reports; other sponsor requests	
2.0	Literature Review & Technology Evaluation (250)															☐ Briefing with detail to assess 1st go/no-go	
3.0	Detect Fluid Flow (250)															☐ Report documenting lab results on detecting small signals	“Go” at 1st go/no-go
4.0	Use TR to Focus Energy (200)															☐ Report documenting lab results on TR focusing of acoustic energy	“Go” at 1st go/no-go
5.0	Detect nonlinear Properties (750+															☐ Final report summarizing lab and field results and data	Successful completion of 4.0
5.1	Lab-scale Experiments (															☐ Initial report on lab results as needed to assess 2nd go/no-go	Successful completion of 4.0
5.2	Field-scale Experiments															☐ Data documenting field performance	“Go” at 2nd go/no-go
6.0	Measure Stress Field															☐ Final report summarizing lab and field results and data	
6.1	Lab-scale Experiments															☐ Initial report on lab results as needed to assess 2nd go/no-go	
6.2	Field-scale Experiments															☐ Data documenting field performance	“Go” at 2nd go/no-go
7.0	Re-assess design criteria															☐ Report assessing feasibility of commercial system based system, along with a development pathway	18

Bibliography

- In Progress