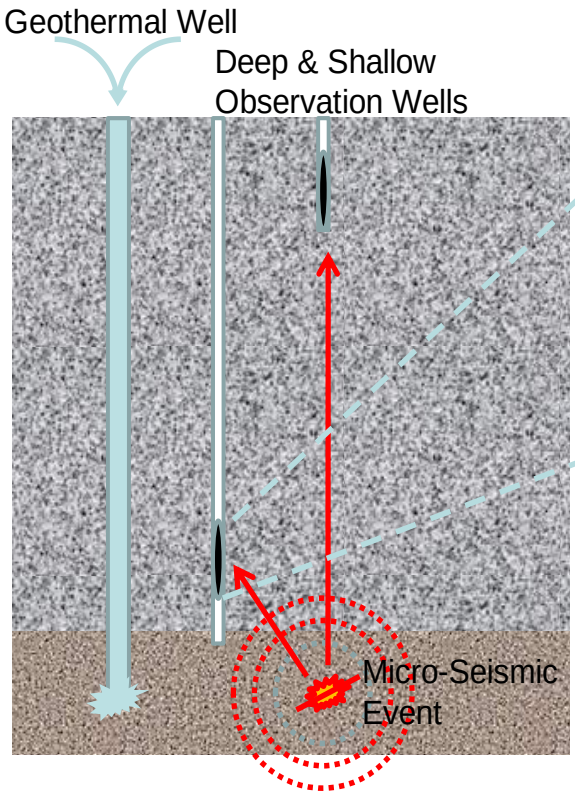
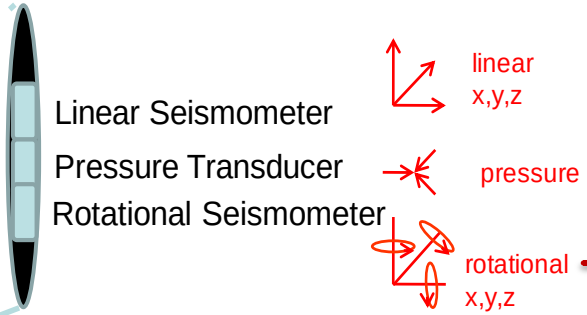
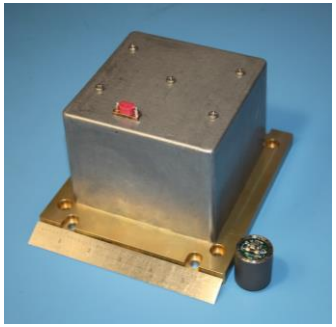


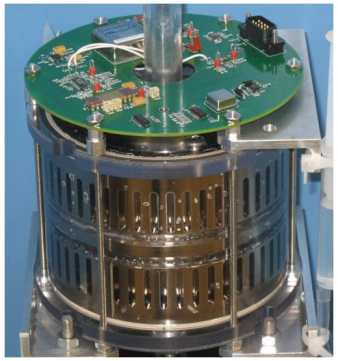


Proposed Rotational-Enabled
7 Degree of Freedom Seismometer

ATA *Applied Technology Associates*



ATA ARS (high-frequency sensor)



ATA LFITS (low-frequency sensor)

Rotation-Enabled 7-DOF Seismometer

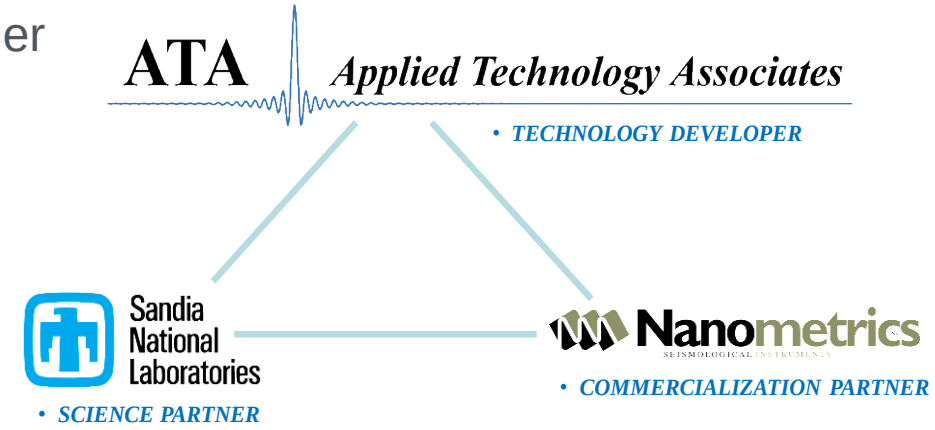
April 22-25, 2013

Principal Investigator: Darren Laughlin
Presenter: Dennis Smith
Organization: ATA / A-Tech

Track 2 – Ballroom B

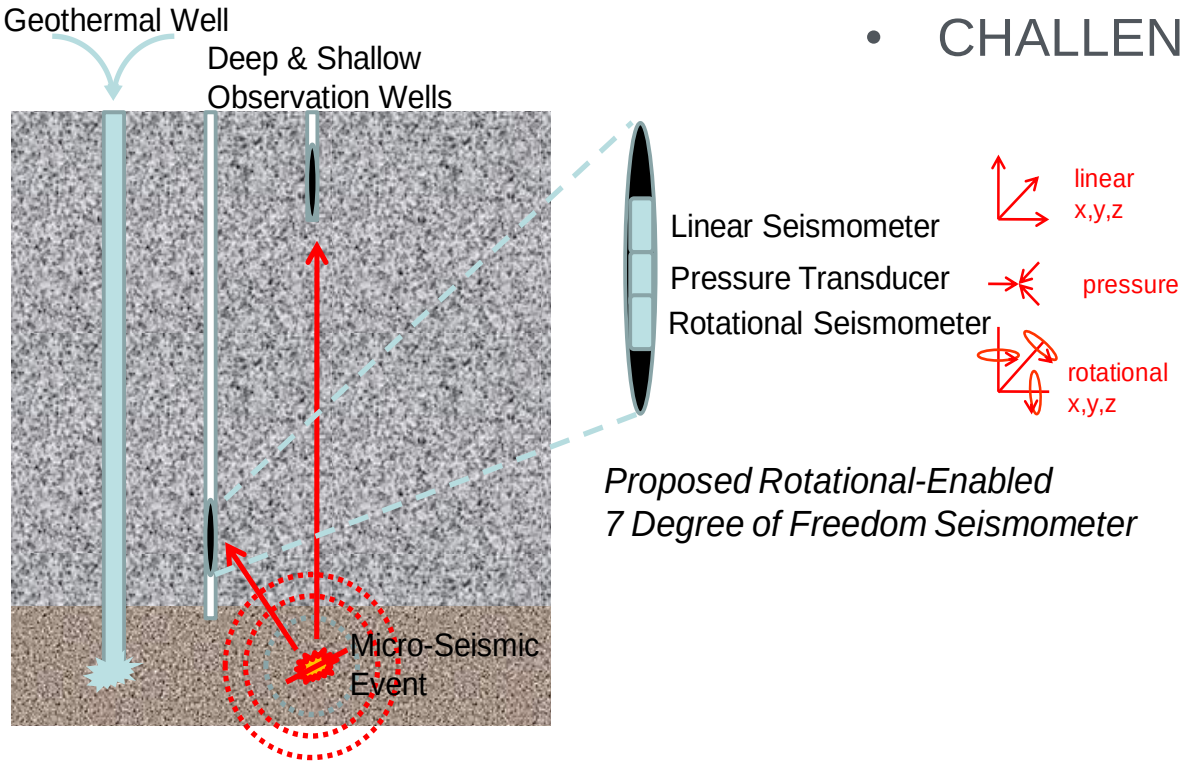
Project Team

- Collaboration Partners:
  - Applied Technology Associates (ATA) / A-Tech
    - Technology Developer
    - Prime / Small Business
  - Sandia National Laboratories (SNL)
    - Science Partner
    - FFRDC
  - Nanometrics, Inc.
    - Commercialization Partner
    - International (Canadian)



Relevance/Impact of Research

- OBJECTIVE: 7 DOF Seismometer for Geothermal Applications
  - Develop a seismic instrument that measures all seven degrees of freedom of the seismic signal including tri-axial rotational sensing in a package suitable for downhole geothermal environments



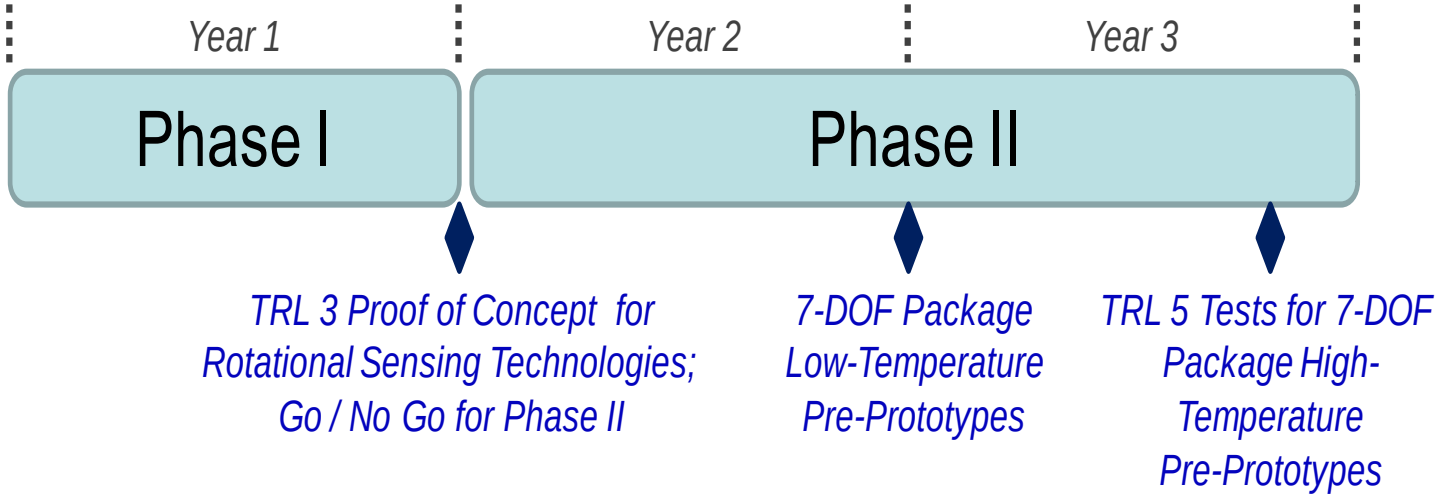
Proposed Rotational-Enabled
7 Degree of Freedom Seismometer

- CHALLENGES Being Addressed:
  - Few if any competent rotational seismic sensors exist even for surface application
  - Nature of rotational signature and relation to crack formation still in research
  - Integrated sensor requires components engineered for geothermal conditions

Relevance/Impact of Research

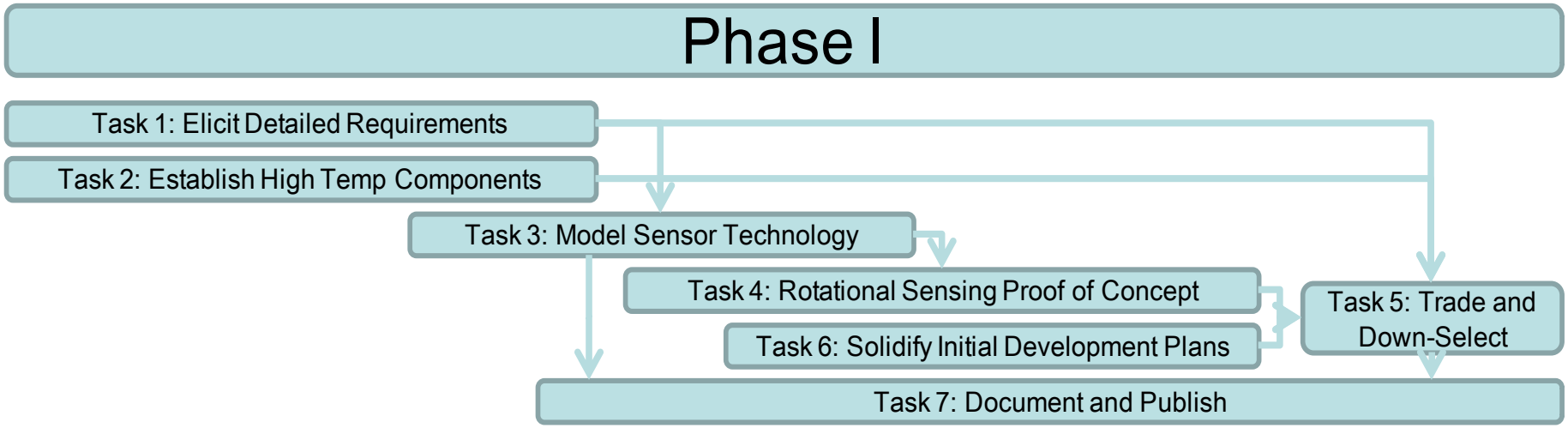
- INNOVATIONS:
  - Full 7-DOF motion measurement capability
    - Enables simultaneous measurement of p-wave, s-wave and velocity and direction
  - Rotational seismometer
    - Based on either ATA Magnetohydrodynamic Angular Rate Sensor (ARS)
      - High-bandwidth; heritage in aerospace applications, but not yet tailored to geothermal application
    - Or ATA Low-Frequency Improved Torsional Seismometer (LFITS)
      - Custom low-noise, low-frequency angular sensor, not yet adapted to geothermal application
    - Or fusion of both for tailored resolution, dynamic range, bandwidth and linear sensitivity
- IMPACT – Potential Cost Saving and Insight Into Evolution of Reservoir:
  - Potential to simplify processing and lower total number of required instruments
  - Provides full measurement of ground motion; enables novel imaging approaches
- GTO GOALS – Project Success Offers:
  - Advancing state-of-art in downhole tools to increase information available to understand the evolution of a reservoir during EGS stimulation activities
  - Enabling lower risk and cost of development and exploration

Scientific/Technical Approach



- Two-Phase Approach with Go / No-Go Gate:
  - Phase I: TRL 3 laboratory proof-of-concept of rotational sensor
    - Two competing rotational sensing technologies
  - Down-select rotational sensing technology and make go / no go decision for Phase II based on feasibility of high temp 7-DOF instrument
  - Phase II: TRL 5 pre-prototypes
    - Low-temp / near-surface sensor
    - High-temp / downhole integrated 7-DOF seismometer

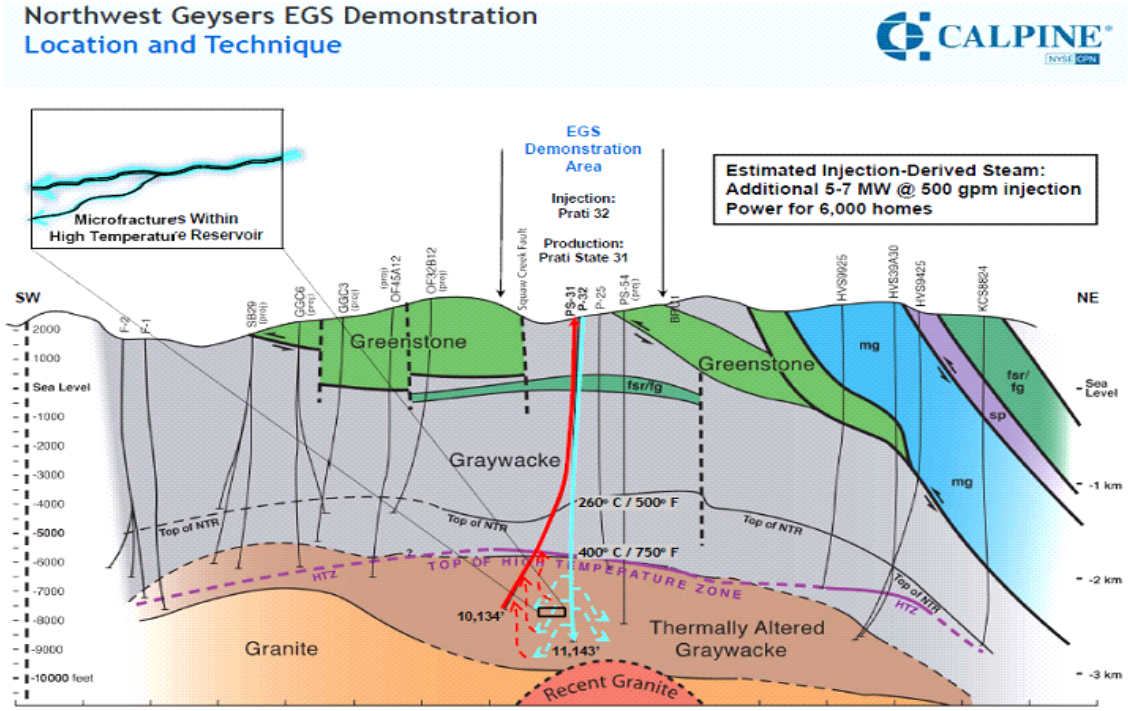
Scientific/Technical Approach

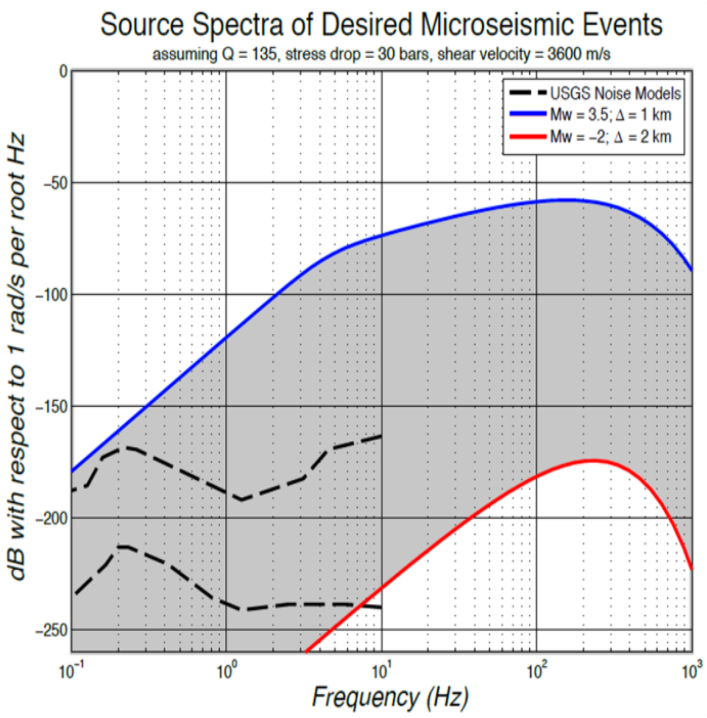


- Phase I: TRL 3 Rotational Sensor Lab Proof-of-Concept
  - Analyze and trade feasibility of two rotational sensing technologies:
    - Elicited and validated requirements for geothermal application
    - Identified suitable components for geothermal environment
    - Modeled and analyzed rotational sensor concepts that would meet requirements
    - Benchmarking models by testing lab brassboards of both technologies
    - Qualifying sensor / measurement tool prospects in development plan
    - Will trade and select best technology to move forward into Phase II

Accomplishments, Results and Progress: Requirements Definition

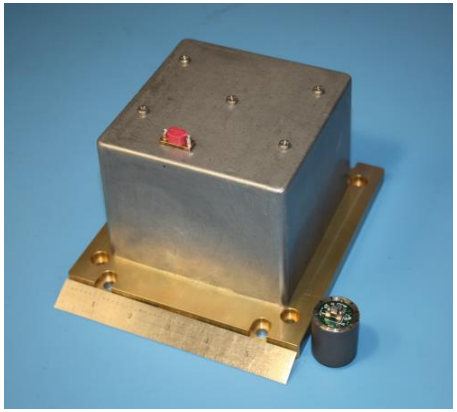
- Developed Requirements for the 7-DOF Instrument (Task 1)
  - Surveyed the literature, sought team's experience examples, and modeled estimates of the expected pressure, linear motion, and rotational motion
    - Across a range of stand-off distances (primarily temperature driven)
    - Earthquake magnitudes from fractures (Mw = -2 to +3.5)
  - Documented final results





Accomplishments, Results and Progress: MHD Technology

- Deployed Custom MHD Angular Rate Sensors(Task 4)
  - Packaged three new-generation ATA ARS-16 broad-band rotational sensors as tri-axial set configured for data acquisition
  - SNL characterized performance at USGS facility
  - SNL deployed to Hawai'i volcanic site for surface recording of earthquakes
  - SNL will deploy at local site for surface recording of downhole explosive shot
- Loaned ATA ARS to USGS Site for Recording Surface Ambient Motion to Augment Requirements Development (Task 1)
  - Also supplied USGS two ARS-24 sensors for parallel lower noise measurements
- Developed Concept for Seismic MHD (SMHD) Instrument
  - Updated existing MHD models for geothermal specific configuration including size and materials (Task 3)
  - Performed engineering analysis for path to high-temperature Seismic MHD (SMHD) (Task 2)

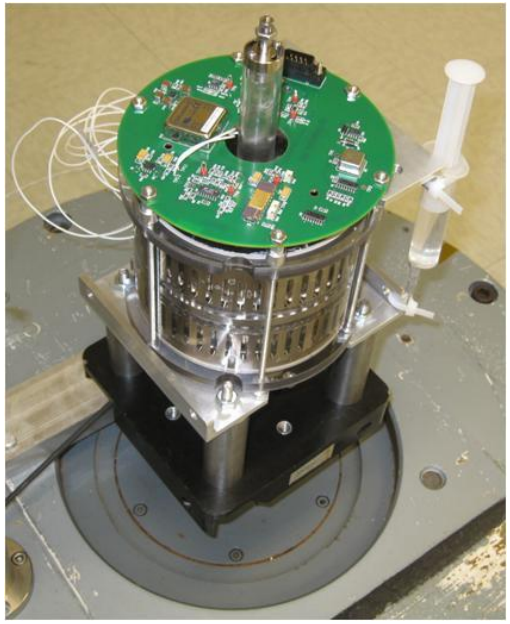


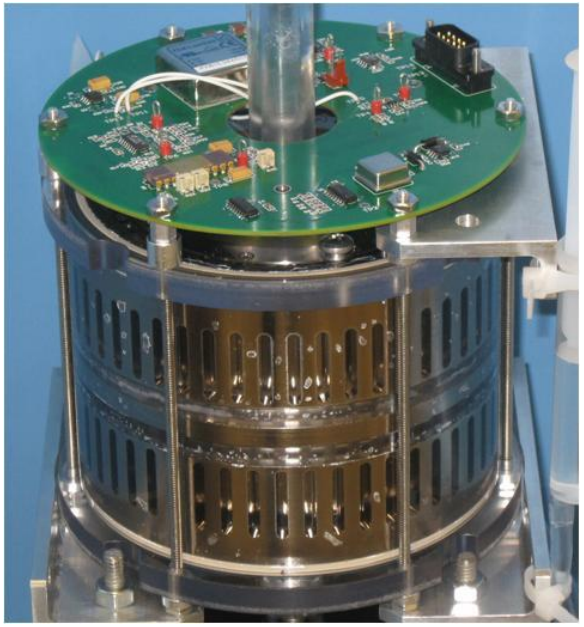
3-Axis ARS-16 MHD

ARS-24

Accomplishments, Results and Progress: LFITS Technology

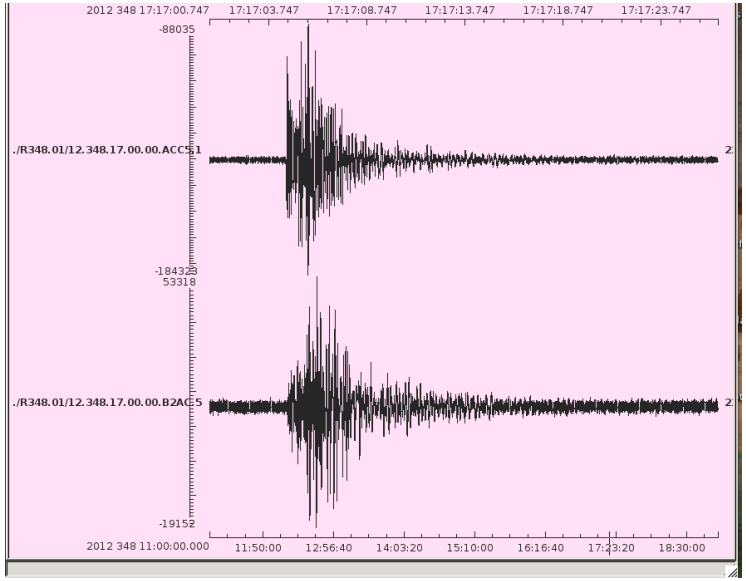
- Developed LFITS Technology Brassboard (Task 4)
  - Developed math model for new sensor (Task 3)
  - Designed proof-of-concept prototype
  - Procured parts and built one LFITS prototype
  - Tested frequency response and compared that with the model's prediction
  - Performed engineering analysis for path to high temperature



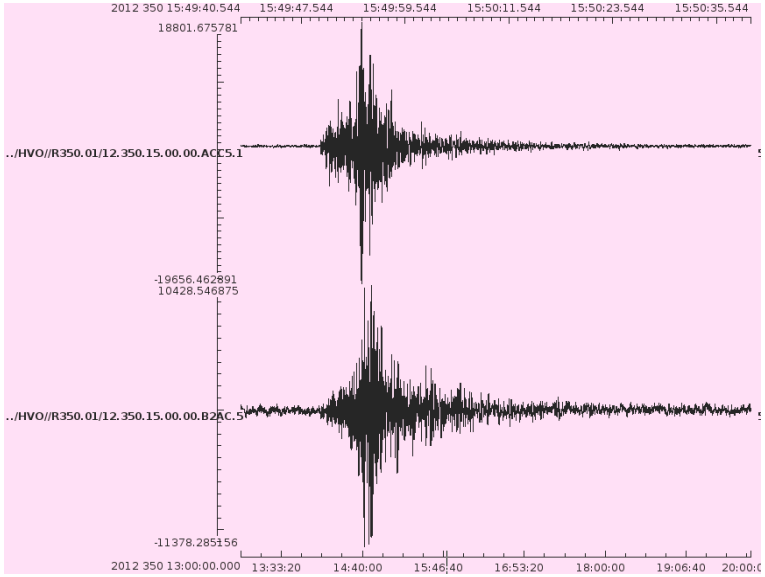


Accomplishments, Results and Progress: Data Sharing

- Types of Data Generated:
  - Research Topical Area of DOE Geothermal Data Repository
    - Tested performance of MHD prototypes at USGS
    - Deployed to Hawai'i to record volcanic activity
    - Deployed to record detonation at Sandia National Labs
  - Reports = Technical Papers / Presentations
    - Paper by Dr. Rob Abbott at the annual SSA meeting14-17 April 2013



Kilauea Earthquake Mw 2, 2 km



Kilauea Earthquake Mw 3.3, 20 km

Accomplishments, Results and Progress: Milestones

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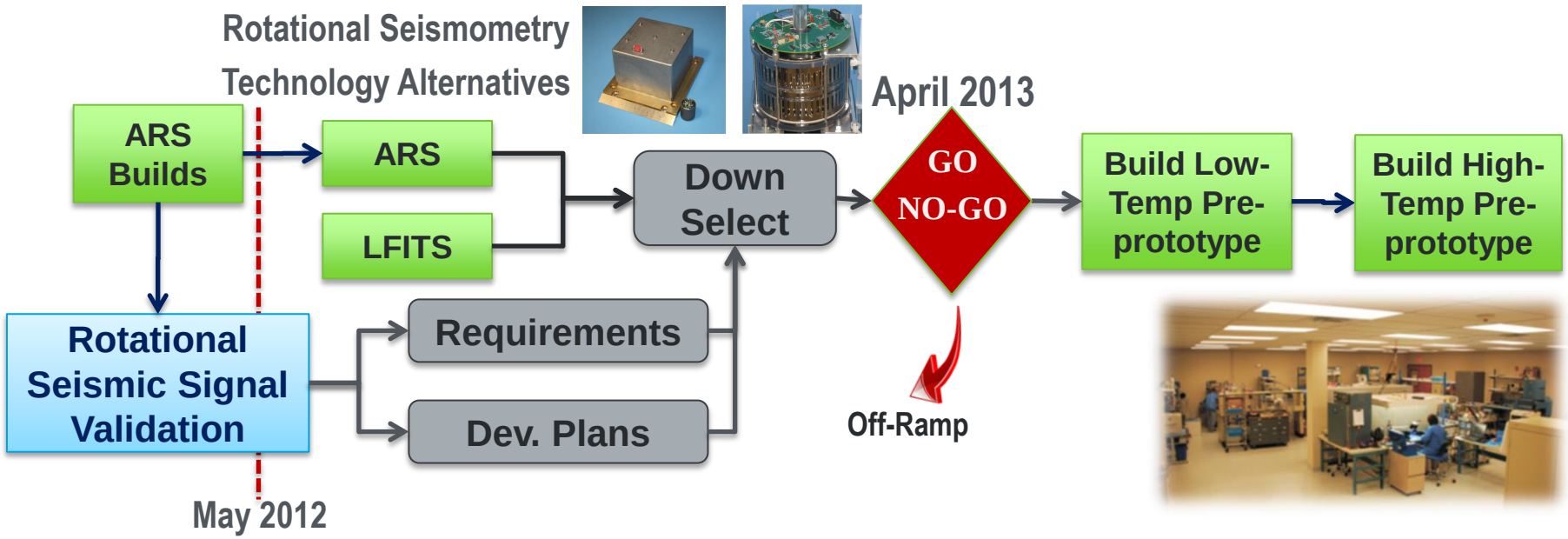
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Task 1 – Complete Initial 7-DOF Instrument Requirements Doc	Completed Initial 7-DOF Instrument Requirements Doc	Feb 2013
Task 2 – Identify Suitable High Temp Components for 7-DOF Instrument	Completed and documented for 7-DOF non-rotational components as well as parts and materials required for rotational sensors	Jan 2013
Task 3 – Develop LFITS Performance Model	Completed in support of LFITS Brassboard Specification Review	Oct 2012
Task 4 – Design and build LFITS Brassboard unit	Completed; unit currently undergoing characterization for comparison to models	Feb 2013
Task 4 – Deploy MHD Brassboard unit for characterization	Completed with USGS and SNL data acquired in relevant environments	Mar 2013

Future Directions: Plans and Deployment Strategy



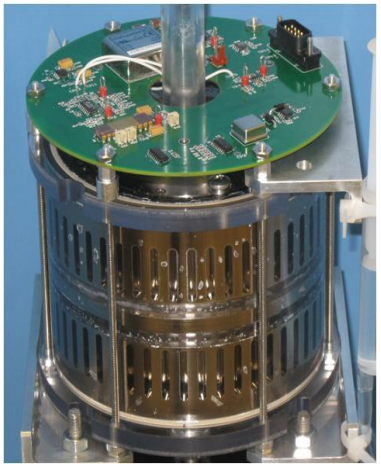
- Phase I Activities Projected to Complete Successfully by 30 April 2013
  - Next Decision Point is Phase II Go / No Go [April 2013]
  - Will be based on feasibility of high temperature downhole 7-DOF instrument
- Deployment Strategy (Phase I)
  - Complete brassboard testing and publish results demonstrating scientific theory of instrument benefit to geothermal applications
- Deployment Strategy (Phase II)
  - Iterate build to get pre-prototypes into hands of first adopters if possible
  - Test, publish and present results of instrumentation tests in community

Future Directions: Milestones

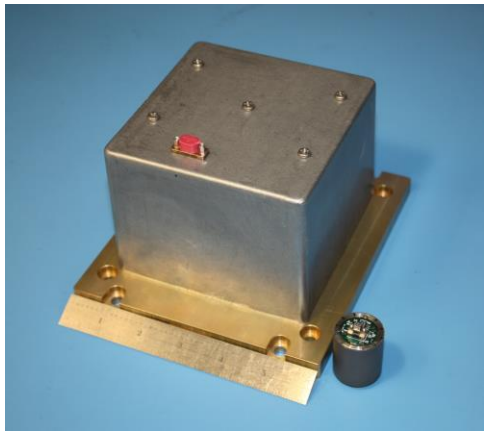
Milestone or Go/No-Go	Status and Expected Completion Date
Task 4 – Complete characterization and Testing of LFITS Brassboard	Close to complete: most of data acquired, analysis in process. Expected completion Mar 2013.
Task 5 – Complete trade study and downselect to one rotational technology for Phase II 7-DOF instrument prototyping	Trade space over requirements established and SMHD data entered; when LFITS data is completed trade study will complete. Expected completion date Apr 2013.
Task 6 – Solidify Initial Development Plans	Task has started with development of high temp SMHD concept design and initial marketing survey by Nanometrics; also addressing materials safety and export controls. Expected completion date Apr 2013.
Task 7 – Document and Publish	Expected completion Apr 2013 with presentation of SNL paper at SSA conference, and publication of Phase I Final Report

Mandatory Summary Slide

- Goal is Full Ground Motion (7-DOF) Characterization
  - Addition of rotational sensing improves characterization of micro-seismic events in downhole instruments
- Phase I Focused on Rotational Seismometer Technology
  - Trade of two technologies includes science/industry input
  - Brassboard hardware built and used to validate detailed models
- Go / No Go Will Be Based on Instrument Feasibility



LFITS Brassboard



MHD Brassboard

ARS-24

Project Management

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

- Initial Schedule Delays
  - The project had some initial delays due to availability of key personnel
  - These were corrected in October and the program has recovered schedule
  - Successful completion of all project tasks is expected by the end of April 2013 as originally planned
- The program leveraged ATA's existing and extensively validated MHD models as well as hardware to use for MHD brassboards
- Our teaming with Sandia National Laboratories and Nanometrics have ensured ATA's technology was linked to both the science and the commercial communities
- Initial discussions have begun with U.S. GeoThermal about potential collaboration on downhole testing of prototypes in the Phase II

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Actual /Est. End Date	
9/30/2011	4/30/2013	9/1/2011	4/30/2013	**Data through Dec 2012**

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$600,000	$150,000	$435,620	$370,185	$371,481	$379,000