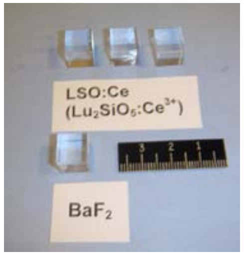
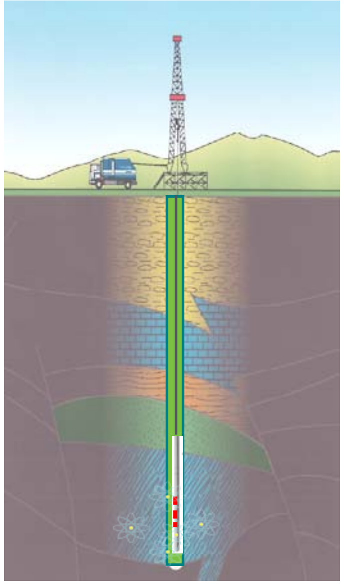




Hatice Akkurt, Zane Bell, Lynn Boatner, John Neal, Peter Chiaro, Mike McCarthy

Feasibility and Design Studies for a High Temperature Downhole Tool

May 19, 2010

Presenter: Hatice Akkurt
Oak Ridge National Laboratory

High Temperature Tools and Sensors

Overview

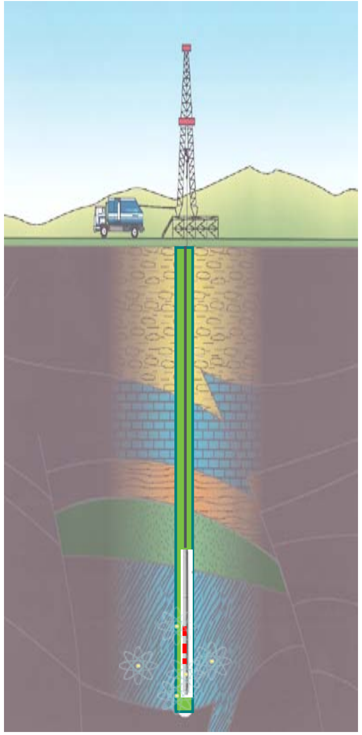
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **Timeline:** 2 years
  - Project Start Date: 10/09
  - Project End Date: 09/11
- **Budget:** Total Project Funding: $976K for two years
  - FY'10 Budget: $476K
  - FY'11 Budget: $500K
- **Goals and Barriers (per Multi Year R&D Plan):**
  - **Goal 3:** Develop improved tools for the characterization and modeling of the subsurface at EGS project sites.
    - Many reservoir characterization technologies already exist and are being used by the geothermal industry or by the oil and gas industry, but technical capabilities must be extended for EGS application.
  - **Barrier C:** High Temperature Logging Tools
    - The technology is commonly used in the oil and gas industry but limited to tools that can operate up to ~150^{o}C

Relevance/Impact of Research

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

Objective: Perform feasibility and design studies for a high temperature downhole tool, which uses nuclear techniques for characterization purposes, using measurements and modeling/simulation



Challenges/Innovative Aspects:

- Hardware Challenges
  - High Temperature; Shock; Vibration
  - Tool size; Cost
- Simulation/Modeling Challenges
  - Lack of nuclear data; quality of nuclear data
  - Modeling detector response
  - Computational time required for reliable answers

Oil and gas industry has considerable experience; HOWEVER, temperatures are limited to 150-170^{o}C. That is WHY the existing tools/technology can not be immediately used in geothermal wells

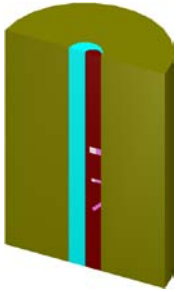
Technical Approach -- Project Tasks

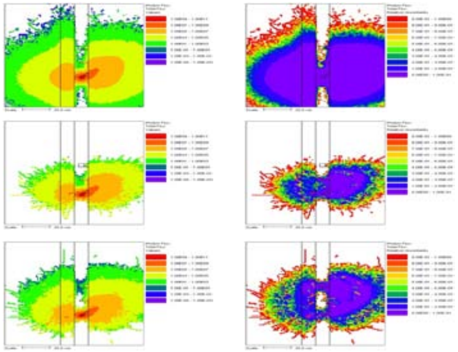
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Investigate the feasibility of development of components enabling operation at temperatures of up to 400^{o}C
  - Evaluation and Testing for Scintillator Materials and Photosensors
  - Evaluation and Testing of Neutron Detector and Moderator Materials
- Modeling/Simulations
  - Determination of detector responses for different temperatures/formations
    - Generation of temperature dependent cross sections
    - Validation of the generated data
  - Validation of modeling results against measured data
  - Tool design
    - How many detectors
    - What type of detectors
    - Placement of detectors & source

Project Management/Coordination

- Management Plan
  - Task leaders are assigned
  - Budget is allocated for each task
  - Monthly meetings to discuss progress and challenges
  - Project is behind spending/schedule due to delay in funding and ordering/delivery times for materials
  - Spending to date: ~35%
- Scope of work re-written for 2 yr plan (instead of 3)
- Leveraging: R&D performed at ORNL for scintillator materials development, testing, and radiation transport modeling sponsored by NNSA and DTRA.





Project Milestones and Deliverables

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

Milestones:

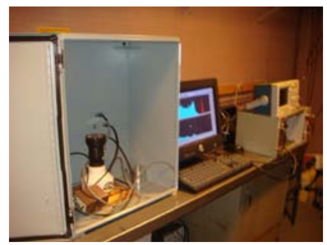
- Evaluate and test the candidate scintillators for temperature.The tests will start at room temperature and increase up to 400^{o}C. Target Date: 09/30/2010
- Evaluate and test the candidate neutron detectors for temperature. Target date: 05/30/2011
- Perform environmental tests, including shock and vibration, on the detectors that passed the temperature tests. Target Date: 07/30/2011.
- Perform simulations to determine the neutron and photon detector response for varying parameters including temperature, formation lithology, porosity, and water content. Generate the nuclear data. Perform benchmark calculations, against measured data, for a subset of the data. Target date: 07/30/2011

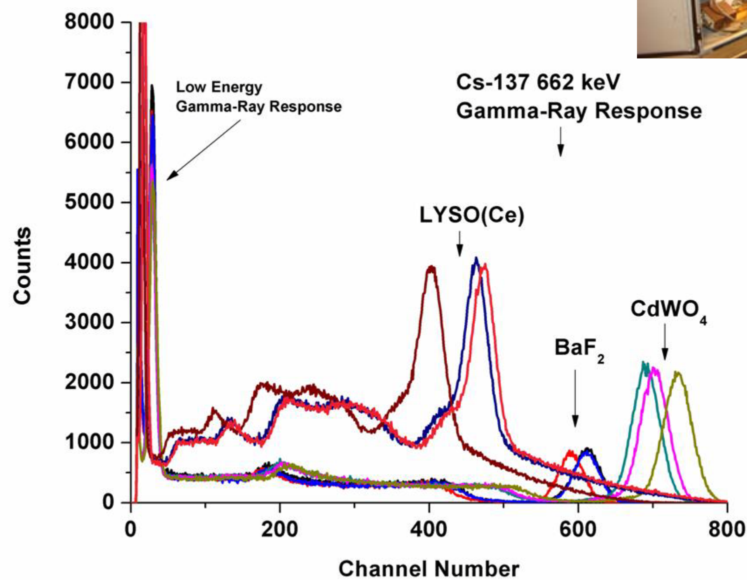
Deliverables:

- A report that summarizes the photon detector temperature tests and findings. Target Date: 11/30/2010
- A report that summarizes the neutron detector temperature tests and findings. Target Date: 07/30/2011
- A report that summarizes the environmental tests and findings. Target Date: 08/30/2011
- A report that summarizes the simulation, modeling results. Target Date: 09/30/2011

Room-Temperature Light Yield and Energy Resolution Tests

- All crystals except for BaF_2 purchased from Hilger Crystals.
- BaF_2 crystals purchased from Princeton Scientific.
- $LaBr_3$ and $LaCl_3$ will either be purchased from Saint Gobain or grown at ORNL.
- SrI_2:Eu and $CeCl_3$ are grown at ORNL.





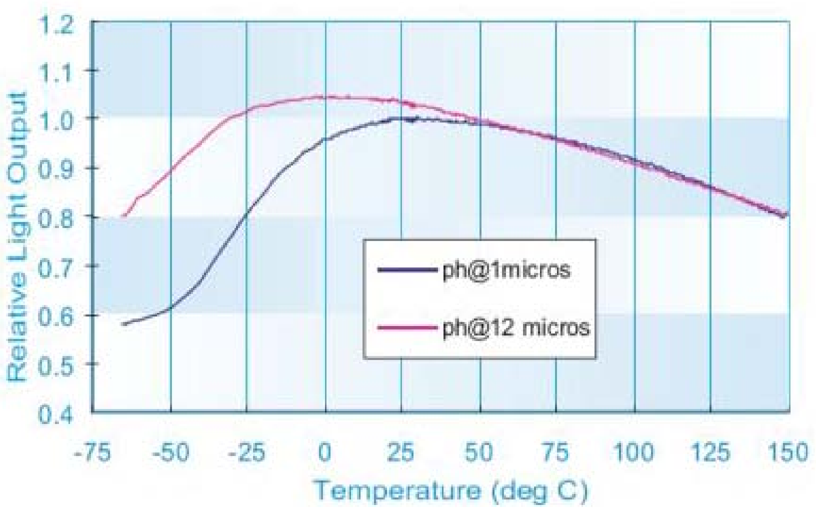
Scintillator Material	Peak Channel #	Av. En. Res. (% at 662 keV)
BGO	461,491, 502	7.7
BaF_2	612,590,611,606	6.7
$CdWO_4$	691,702,733	6.2
$ZnWO_4$	524,352,534	9.1
NaI	537	11.7
CsI	397,403,417	13.6
CsI(Na)	521,483	5.8
CsI(Tl)	526,521,534	5.4
LSO(Ce)	406,413,416	13.4
LYSO(Ce)	464,404,474	6.7
LuAP(Ce)	260,258,262	6.9
YAG(Ce)	224,218,224	7.8
YAP(Ce)	795,795,807	3.3

Peak channel # values in red are significantly different than other measured values

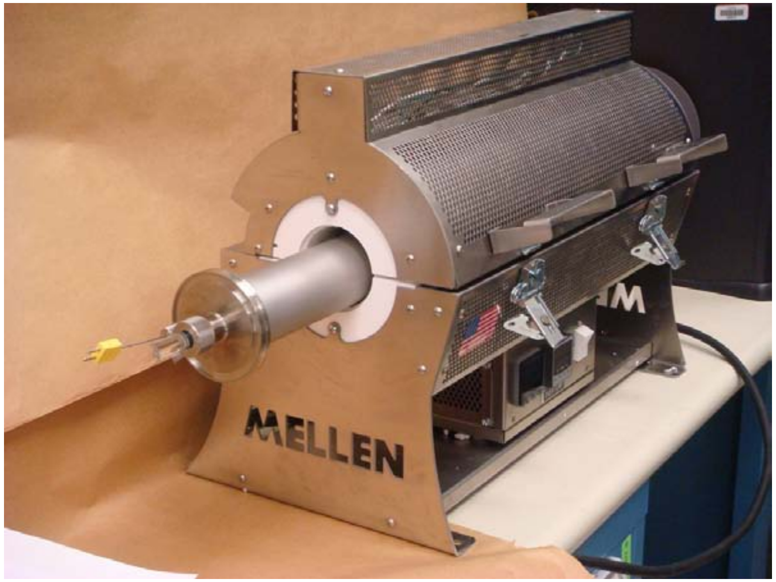
High-Temperature Light Yield and Energy Resolution Tests

Testing Protocol

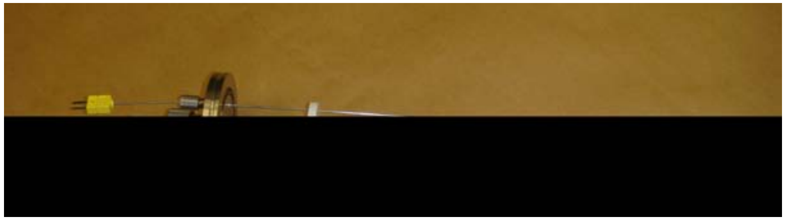
- Light yield and energy resolution measurements (at 662 keV) at room temperature, 25ºC, 50ºC,….400ºC
- Test additional (non-commercial) scintillators like SrI_2:Eu and $CeCl_3$ under same conditions



Temperature Response of NaI(Tl) Crystals From Saint-Gobain Crystals NaI(Tl) Data Sheet



Furnace for High-Temperature Scintillator and ^{3}He Tube Testing



Neutron Detectors & Moderator Materials

Neutron Detector

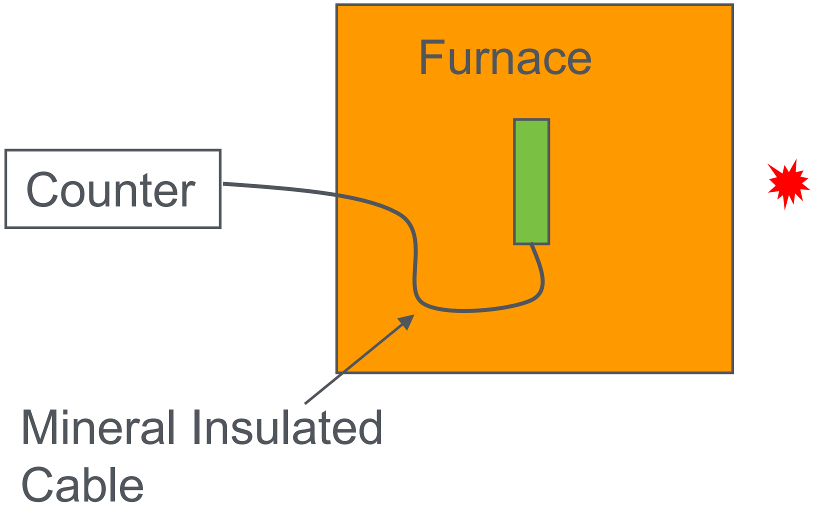
- ^{3}He
  - Workhorse of the industry
  - Tubes are not rated beyond ~200ºC
  - National shortage of ^{3}He
  - Tubes on order from Reuter-Stokes
  - Agreed to supply best-effort 30 cm x 2.5 cm Ø tubes
  - Brazing may fail (not likely)
  - Insulator becomes noisy (more likely)
- Fission chamber
  - Rated for in/ex-core use to 600ºC
  - Sensitivity up to 1 cps/(n/cm^2/s)
  - Contains ^{235}U
  - ~ €65,000 for 23 cm long x 5 cm Ø

Moderator Materials

- Hydrogenous moderator (lowest Z, A)
  - PE: m.p. 120 – 130ºC
  - PP: m.p. 165 ºC
  - Other hydrocarbons similar or decompose
  - PEEK: 340ºC, commercially available
  - Polyimide: 388ºC, commercially available
  - Manufacturers are interested in working with us to establish a new use
- Exotic options (low Z, A):
  - $^{11}B_4C$, graphite, $Be^{11}B_6$, $Be_2{}^{11}B$, $Be_4{}^{11}B$
  - US Patent 3,863,541 teaches how to make pellets of Be borides
  - B_4C is commercially available
  - ORNL has presses to make compacts

Neutron Detectors – Test plan

- Measure response as a function of temperature
- Use same furnace as for scintillator measurements
- Raise temperature, hold, measure, repeat

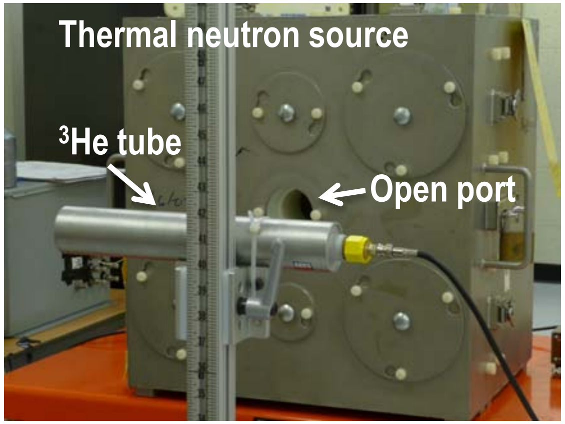


Available Neutron Sources

- AmLi thermalized neutron source

  7 ports (2.5 – 10 cm), no cover

  50 – 100 n/cm^2/s
- AmBe and D-T available



Environmental Test Plan

Phase 1

1) Characterize scintillation vs thermal properties of candidate crystals.

2) Subject scintillators to shock and vibration regiment.

3) Remeasure scintillation properties. Prepare preliminary report.

Phase 2

1. Subject the surviving scintillators to combined thermal and vibration effects
2. Record their scintillation properties in real time.

- A crystal holder capable of holding detectors at high temperature and shock loads is being developed

Scintillation Crystal Fixture

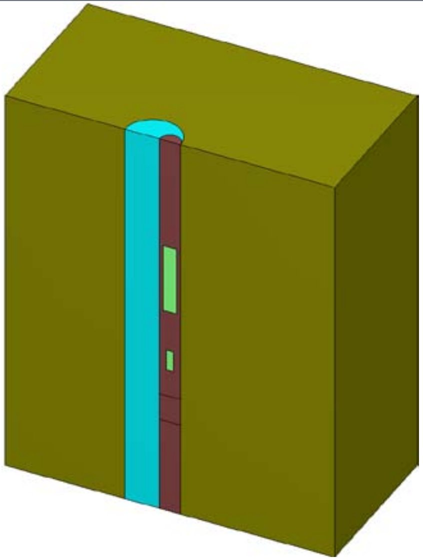
Programmable Shaker Table

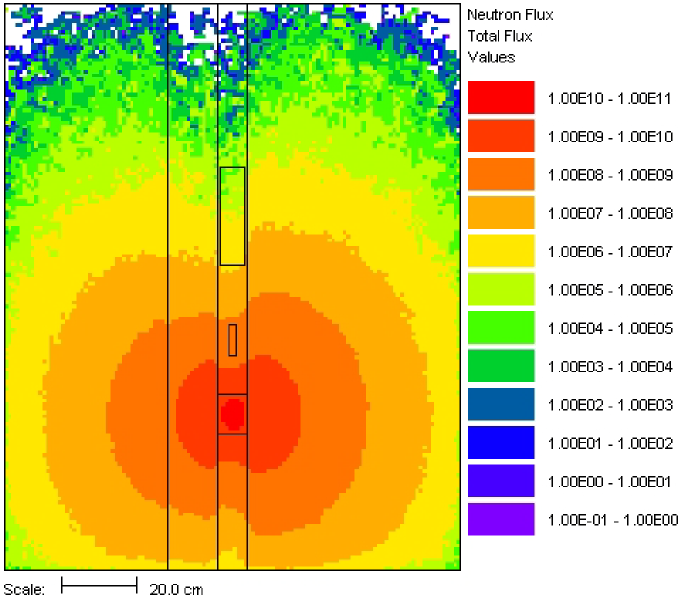
- A programmable shaker table will be used to simulate the vibration environment in a geothermal drill bit.

Simulation/Modeling Progress and Plans

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

- Generated the temperature dependent nuclear data using NJOY code
  - Started from room temperature and generated data up to 400°C with 50°C increments for all major nuclides
- Validated the generated data against existing data (room temp) to ensure consistency in results
- MCNP simulations are being performed to determine response for varying temperature and formation.
- The computational results will also be benchmarked against other codes (deterministic: DENOVO, hybrid: ADVANTG).
- The computational results will also be benchmarked against measured values for a selected subset for validation purposes.





Future Directions

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

Year 1 Tasks:

- Temperature tests for commercially available scintillatormaterials and neutron detectors
- Preparation of apparatus for environmental tests
- Simulation modeling: Generation of temperature dependent data, validation of this data, and performing simple benchmark measurements to validate against computational results

Year 2 Tasks:

- Temperature tests for remaining non-commercial scintillators (grown at ORNL), photosensors, neutron detectors and moderators
- Environmental tests for vibration and shock
- Simulation modeling results for different environments, temperature. Benchmark calculation results.

Year 2 Deliverables: Reports that describe the temperature, environmental tests for neutron, photon detectors and photosensors. Another report that describes that simulation approach and modeling results.

If our efforts are successful, will partner with others in industry and/or National laboratories to develop a prototype tool

Feasibility and Design Studies for a High Temperature Down Hole Tool -- Summary

- COMPLETED
  - Room temperature scintillator light yield and energy resolution
  - Temperature-adjusted nuclear data
- IN PROGRESS
  - Setup for temperature tests
  - Equipment procurement
  - Setup for mechanical tests
  - Test plans for temperature and environmental tests
  - Simulations of temperature-dependent radiation transport
  - Validation of high-temperature nuclear data
- TO BE STARTED
  - Initial tests for temperature tests for scintillators.
  - Initial tests for fission chambers.