# US DOE Protocol/Best Practices for Induced Seismicity

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# Reasons for a IS Protocol

- ***Means for guiding all stakeholders in addressing safety issues surrounding EGS***
  - Provide guidelines for a geothermal developer to deal with the concerns of induced seismicity.
  - Inform and interact with the other stakeholders to understand their concerns and partner with them to achieve a win-win situation
- ***Technical***
  - Identify and understand factors controlling microseismicity
  - Effect of microseismicity on EGS development
  - Use IS as a method to understand the reservoir creation process

Both are linked and overlapping

# Motivation

- Current IEA Protocol was developed in 2007
  - New information on EGS induced seismicity
  - New experiences with induced seismicity
  - Heightened concerns by regulators and public
- U.S Policy makers wanted a protocol for US industry
- Industry/investors need to calculate risk and uncertainty
- Some concepts outdated or incomplete
  - Magnitude versus ground motion
  - Mitigation measures
  - Risk versus hazard assessment
  - Stakeholders interactions

# Protocol: General Approach

- Not a regulatory document but to be used as a general guideline
  - Operators still required to meet all local, state, and/or federal regulations
- Recognize that one "size does not fit all"
  - Different EGS projects will have different needs and requirements
- Written for all stakeholders
  - Policy makers, regulators, public, developers
- Living document
  - Supplement IEA-GIA Protocol and intended to be updated as knowledge and experience gained
- Base recommendations on existing and accepted engineering standards
  - mining, construction, etc.
- Also suggests when it does not apply
  - Shallow heat pump or shallow injections for water recharge ( few hundred meters), etc.
- Meant to be accompanied by a "best practices" technical " document ( for operators mainly)

# The 7 Main Steps

- 1. Perform a preliminary screening evaluation
- 2. Implement an outreach and communication program
- 3. Identify criteria for ground vibration and noise
- 4. Seismic monitoring
- 5. Quantify the hazard from natural and induced seismic events
- 6. Characterize the risk from induced seismic events
- 7. Develop risk-based mitigation plans

# The 7 main steps

- 1. Perform Preliminary Screening Evaluation
  - Purpose: Identify any factors that will automatically disqualify a site from being a successful EGS site (W.R.T. induced seismicity)
    - Known induced seismicity history.
    - In the middle of a city in a known seismogenic zone?
    - Near sensitive facilities ( historical artifacts, hospitals, etc)
    - Near large faults ( ones that may generate events larger than acceptable levels)
    - Hostile public
    - Etc.

# 7 Steps continued

- 2. Implement an Outreach and Communication Program
  - Purpose: facilitate communication and maintain positive relationships with the local community, stakeholders, regulators, and public safety officials.
    - Extensive and comprehensive stakeholder out reach
    - Supply timely, open, and complete information
    - Explain  benefits  and risks
    - Review laws and regulations
    - Establish dialogue with regional authority and community
    - Continual interaction and public  interaction

# 7 steps continued

- 3. Review and Select Criteria for Ground Vibration and Noise
  - Purpose: identify and evaluate existing standards and criteria, identify existing noise and vibration standards and mitigation measures that have been developed and applied by other industries, and that could be helpful in evaluating the EGS project .
    - Determine maximum allowable ground motion (can be defined by laws governing vibration from blasting , mining , construction, from both single event and continuous sources, public concerns ,etc)
    - Numerous criteria, standards, and equipment specifications exist that may be drawn upon in assessing the impact of EGS seismicity on neighboring communities. These should be reviewed in detail and used to develop appropriate criteria for risk assessment.
    - Some of the information may be directly applicable to EGS, but most would likely require some adjustment, considering the short duration and unpredictability of induced seismic events.
    - Additional criteria can be found. For example, European countries where EGS activities have been developed are considering EGS-specific impact assessment criteria or mitigation design provisions.

# 7 steps continued

- 4. Seismic Monitoring and Analysis
  - Purpose: Gather data on seismicity to supplement existing seismic data and provide seismic data in the vicinity of the EGS area to forecast induced seismicity activity, and understand induced seismicity for mitigation and reservoir management purposes.
    - Historical and baseline seismicity in the region
      - To be used for risk assessment of natural seismicity
      - May need to augment with additional stations
    - Implement background and injection/post injection monitoring (real time, publically available)
    - Seismic monitoring should be commenced as soon as a project site is selected.
    - Comprehensive enough to allow complete spatial coverage of background or baseline seismicity over an area that is at least twice as large as the largest anticipated enhanced reservoir.
    - The monitoring should be maintained for the lifetime of the project and possibly longer, depending on seismicity created and volume affected.
    - Instrumentation should be able to detect events at least as small as **M** 1.0 and preferably to **M** 0.0. or less depending on EGS area

# 7 steps continued

- 5. Quantify the Hazard from Natural and Induced Seismic Events (how much and how big)
  - Purpose: Estimate the ground shaking hazard at a proposed EGS site due to natural seismicity, and induced seismicity, to provide a *baseline* from which to evaluate the additional hazard from induced seismicity.
    - Should be performed before any geothermal stimulations and operations are initiated.
    - Will require  data on geology/structure, stress , etc depending on model
    - Estimate the Baseline Hazard from Natural Seismicity
      - PSHA
      - Deterministic
    - Estimate the Hazard from Induced Seismicity
      - Physics based PSHA
      - Deterministic, analog, case histories
      - Model (rock physics, poro-elastic, diffusion, thermal ,etc)

# Step 5 Needs

- Stress properties
- Injection designs and thermal characteristics
- Local (borehole) and regional stress state and directions controls fracture direction and all sorts of things (frac gradient, height, orientation, width, etc) as well as ability to connect to other wells.
- Rock Type/lithology, controls fracture initiation and complexity/ natural propping success, fracture/fault dimensions.
- Rock matrix permeability, mineralogy and variability( scaling , plugging).
- Pre-existing fracture/fault content and type, affects fracture connectivity and induced fracture complexity
- Fluid content/pore pressure affects fracture fluid properties and overall design, rock fluid interaction

# 7 steps continued

- 6. Characterize the Risk of Induced Seismic Events
  - Purpose: develop a rigorous and credible estimate of the risk associated with the design, construction, and operation of the proposed EGS facility
    - To compare the future expected risk associated with the operation to the baseline risk existing prior to operation.
    - The dominant risk is associated with events that have low magnitudes and cause low to very low ground motions (annoyance versus damage).
    - Identify the assets that could be adversely affected and that could contribute to the total risk.
    - Characterize the damage potential (vulnerability) from the risk contributors.
    - Estimate the risk. (risk = consequence X prob of occurrence)
    - Present the results. (maps, shake maps, etc)

# 7 steps continued

- 7. Develop Risk Based Mitigation Plan
  - Purpose: Suggest both direct and indirect mitigation measures.
    - Direct (engineered) (recognize mitigation measures will not instantly work)
      - Modify injection rates patterns volumes, etc
      - Strengthen affected structures
    - Indirect
      - Increased out reach
      - Increased community communication
      - Financial support
    - Legal aspects
      - Recognize that legal concepts such as trespass, nuisance, etc, even if the seismicity causes little physical damage."

    I.E., Early in the project prepare mitigation plans that focus on both the operations themselves and the nuisance or damage that might result from those operations.

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# What could/should we do?- Operational

- Deploy advanced monitoring systems
  - High sensitivity/low noise, wide bandwidth and dynamic range) ( experimental data)
  - continuous data-stream as basis for operational control decisions during development and long-term operation
- Risk-based decision making for operational control
  - Link probabilistic seismic hazard/risk method with physics-based approach (incorporating uncertainty)
  - Improved “stop light” methods
- Mitigation and Control Procedures
  - Site characterization and selection; faults, communities
  - Engineering design – well locations, injection pressures, etc.
  - Data-driven operational control
- Establish a best practices/protocol based on accepted scientific knowledge in order to allow implementation of energy projects – i.e set out the rules!!

# What should/could be done? –Research Needs

- Quantify relation between seismicity and permeability enhancement
- Improve means to quantify the relation between stress change and seismicity rate?
- Is there time dependence or stressing rate dependence in stress-seismicity rate changes/ or is the theory of effective stress all we need to know?
- Improved data and methods for processing low magnitude events
  - i.e improved Green's functions ( better velocity and attenuation models: 50 m scale)
- Determine role of mechanical processes (fault healing, permeability reduction) versus other changes in the induced seismicity generation
  - What do we need to know about fault zone poroelasticity?
  - What do we need to know about chemical processes?
- Do induced earthquakes follow the same decay relations as tectonic earthquakes in the same province? (why or why not)
- Active experiments to manipulate seismicity without compromising production
  - reservoir performance assessment
  - integrated reservoir analysis

**Dedicated test sites for exploring research issues?**