INL/LTD-16-38124 R1
DE-EE0007159

The Snake River Geothermal Consortium is a research partnership focused on advancing geothermal energy, hosted by Idaho National Laboratory.

Preliminary Induced Seismicity Mitigation Plan

April 2016

SRG Consortium | Snake River Geothermal

FORGE
U.S. Department of Energy

INL/LTD-16-38124 R1

Preliminary Induced Seismicity Mitigation Plan

Dennise Templeton, Lawrence Livermore National Laboratory
Rob Mellors, Lawrence Livermore National Laboratory
Suzette Payne, Idaho National Laboratory
John Irving, Idaho National Laboratory
Julie Ulrich, Idaho National Laboratory
Robert K. Podgorney, Idaho National Laboratory

April 2016

Snake River Geothermal Consortium
Hosted by Idaho National Laboratory
Idaho Falls, Idaho

www.snakerivergeothermal.org

Prepared for the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

EXECUTIVE SUMMARY

This plan describes the protocol that will be used to mitigate any negative consequences of induced seismicity resulting from the Frontier Observatory for Research in Geothermal Energy (FORGE). FORGE marks the U.S. Department of Energy's (DOE's) largest effort to advance the deployment of enhanced geothermal systems (EGS), which have the potential to tap into a conservatively estimated 100 GW of baseload power-generating capacity by harnessing the earth's heat through engineered geothermal reservoirs. This project is being conducted by the Snake River Geothermal Consortium (SRGC) at the 110-km^2 (42.6-mi^2) Geothermal Resource Research Area on the Idaho National Laboratory Site.

Our plan follows the DOE's *Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems* and the *Best Practices for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems*. The protocol consists of seven steps: (1) perform a preliminary screening, (2) implement a communications and outreach program, (3) review criteria for ground vibration and noise, (4) establish seismic monitoring, (5) quantify the seismic hazard, (6) characterize seismic risk, and (7) develop a risk-based mitigation plan.

Our preliminary screening, as based on the guidelines presented in documents mentioned above, suggests that induced seismicity at the FORGE site presents a low overall risk given the favorable regulatory environment (DOE and the Bureau of Land Management), limited radius of influence, and low impact.

Our communications and outreach program began in 2012 with preparatory meetings with key community, regulatory, and government stakeholders. Our approach has included meetings, presentations, websites, social media, and K-12 and higher educational activities. These activities will continue throughout the project, with content tailored to the overall EGS project stage. During stimulation, particular focus will be given to potential induced seismicity. In the post-stimulation phase, outreach will include an increasing component of technical outreach (e.g., publishing and presenting research results). Assessment and iterative improvement of the communications and outreach program will be ongoing.

Seismic monitoring is a key element of EGS development. The FORGE site is well-equipped for this monitoring with an existing 33-station (surface and borehole) telemetered network that already achieves the requirements in the protocol mentioned above. In addition, an extensive high-quality catalog dating from 1972 permits an accurate characterization of all seismogenic structures near the FORGE site. A Global Positioning System network also spans the area. Additional seismic stations will be installed during Phase 2 of the FORGE project for high-resolution monitoring and characterization of the site. During stimulation, near real-time monitoring will be conducted with predefined thresholds to mark exceptional events that warrant further attention. Monitoring will also include vibration monitoring in accordance with local regulations.

Extensive seismic hazard and risk analyses have been performed for facilities at the INL Site, and these will be used as the foundation for seismic hazard analysis specific to the FORGE project. The existing probabilistic seismic hazard analyses indicate that the seismic hazard is almost entirely from Basin and Range events outside the boundaries of the Snake River Plain, upon which the INL Site is located, and that faults within the Snake River Plain, which are mostly related to minor volcanic rifts, contribute little hazard. The specific EGS probabilistic seismic hazard analysis will include the hazard from induced events as well as natural events. The risk depends on the seismic hazard and the potential impact, including physical damage to facilities or smaller events that affect quality of life. INL has significant facilities within 20 km (12.4 mi) of the FORGE site, but all of them have been designed to withstand substantial ground motions from natural seismicity. Induced seismicity is extremely unlikely to produce the level of ground motion produced by natural seismicity, so the risk is low.

Risk mitigation will be based on two primary elements: (1) a “traffic light” system that defines responses based on levels of ground motion and (2) education and outreach efforts. Because no significant seismic events are expected, the primary goal is to address the nuisance effect.

During Phase 2 of the FORGE project, a clear set of objectives will be defined to develop the final seismic mitigation plan. Key elements include establishment of a seismic monitoring system in addition to the existing system and refinement of the hazard, risk, and risk-mitigation elements. These will be conducted in parallel with a robust outreach and communication strategy.

CONTENTS

FIGURES

TABLES

ACRONYMS

ATR	Advance Test Reactor
BEA	Battelle Energy Alliance, LLC
CAES	Center for Advanced Energy Studies
CIFC	City of Idaho Falls Code
DOE	U.S. Department of Energy
DOE-ID	U.S. Department of Energy Idaho Operations Office
EGS	enhanced geothermal systems
ESRP	Eastern Snake River Plain
FORGE	Frontier Observatory for Research in Geothermal Energy
GPS	Global Positioning System
GRRA	Geothermal Resource Research Area
IDAPA	Idaho Administrative Procedures Act
IDWR	Idaho Department of Water Resources
INL	Idaho National Laboratory
INTEC	Idaho Nuclear and Engineering Technology Center
K-12	kindergarten through twelfth grade
M	magnitude
M_D	duration magnitude
M_L	local magnitude
Mw	moment magnitude
NEPA	National Environmental Policy Act
NRF	Naval Reactors Facility
PDF	probability density function
PGA	peak ground acceleration
PSHA	probabilistic seismic hazard analysis
PGV	peak ground velocity
SRGC	Snake River Geothermal Consortium
SRP	Snake River Plain
VRZ	volcanic rift zone

Preliminary Induced Seismicity Mitigation Plan

1. INTRODUCTION

This plan describes the protocol that will be used to mitigate any negative consequences of induced seismicity from the Frontier Observatory for Research in Geothermal Energy (FORGE). FORGE marks the U.S. Department of Energy's (DOE's) largest effort to advance the deployment of enhanced geothermal systems (EGS). EGS has the potential to tap into a conservatively estimated 100 GW of baseload power-generating capacity by harnessing the earth's heat through engineered geothermal reservoirs. The FORGE project aims to develop methodologies and technologies that will bring this resource into the nation's energy portfolio (Metcalfe, 2015). This project is being performed by the Snake River Geothermal Consortium (SRGC) at the 110-km^2 (42.6-mi^2) Geothermal Resource Research Area (GRRA) on the Idaho National Laboratory (INL) Site.

Our plan follows the DOE's *Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems* (Majer et al., 2012) and the *Best Practices for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems (EGS)* (Majer et al., 2014). The protocol outlines a set of seven steps to mitigate induced seismicity:

1. Perform a preliminary screening evaluation
2. Implement a communications and outreach program
3. Review and select criteria for ground vibration and noise
4. Establish seismic monitoring
5. Quantify the hazard from natural and induced seismic events
6. Characterize seismic risk
7. Develop a risk-based mitigation plan.

Described here are our data, methodology, plan, and/or results for each of these steps.

Section 2, Preliminary Screening Evaluation, is designed to assess the technical feasibility of the project and to measure the acceptability of the project to pertinent stakeholders. Section 3, Communications and Outreach Program, contains static, dynamic, and multi-directional components of information exchange between the SRGC and local community, regulatory, and government stakeholders. The communications and outreach program described here is closely coordinated and integrated with the project's *Communications and Outreach Plan* (Ulrich and Podgorney, 2016). Section 4, Ground Vibration and Noise, evaluates existing standards and criteria for ground-borne noise and vibrations and describes the existing conditions at the INL Site. Section 5, Seismic Monitoring, describes the existing seismic monitoring program, which is gathering baseline seismic data, as well the proposed additional seismic stations and procedures for future phases of the project. Key technical information and results are presented in Section 6, Seismic Hazard from Natural and Induced Seismic Events, to compare the risk associated with natural and induced seismic events. Using the seismic hazard results, we next describe the methodology available (see Section 7, Seismic Risk Analysis). Section 8, Risk-Based Mitigation Plan, describes sources of risk from the project and suggested mitigation measures. Section 9, Conclusion, is a summary of the analyses presented in this plan. In Section 10, Phase 2 Plan, we describe the analyses that will be included in the final version of this plan.

2. PRELIMINARY SCREENING EVALUATION

The FORGE facility will be located within the GRRA at the INL Site, which is situated on the Snake River Plain (SRP). The GRRA is a dedicated research area of approximately 110 km^2 (42.6 mi^2) of secure, contiguous DOE land at the western edge of the INL Site (Figure 1). This parcel is within Butte County, Idaho, and was withdrawn from public use in 1958.

Our preliminary screening evaluation is designed to assess the feasibility of the project and to measure the acceptability of the project to pertinent stakeholders. Preliminary screening requires consideration of four major factors: review of relevant regulations, the expected radius of influence of any seismic activity, the potential impacts, and the approximate potential damages. After an initial evaluation of the four factors, which are presented in greater detail below, we gauge the overall risk as low with no incompatible conditions, and we will conduct additional analysis in Phase 2 to further refine the radius of impact and bounds on potential damage from induced seismicity.

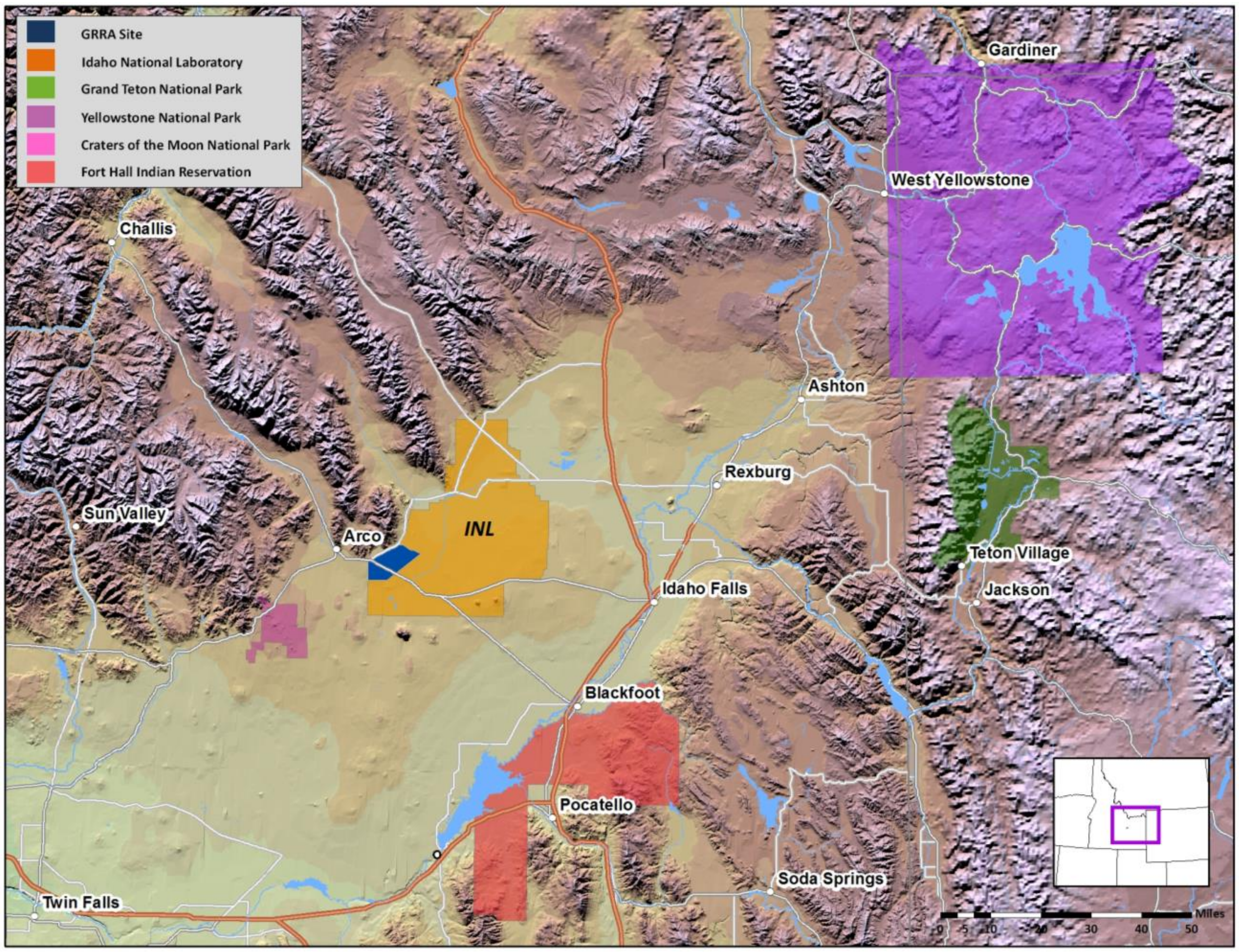


Figure 1. Map showing the INL Site and the GRRA in relation to surrounding features, such as nearby cities, national parks, a national monument, and the Fort Hall Indian Reservation.

2.1 Review of Laws and Regulations

The federal agencies responsible for regulatory oversight of the GRRA are DOE and the Bureau of Land Management. Under the National Environmental Policy Act (NEPA) (42 U.S.C. §§4321-4370h), DOE will require an environmental assessment for the FORGE project to determine if an environmental impact statement is required. The SRGC has an in-house NEPA group that works closely with the DOE Idaho Operations Office (DOE-ID), which is the DOE entity charged with overseeing INL operations. The laws and regulations found in this plan have been identified through a careful review process in Phase 1 of the FORGE project. DOE may identify additional requirements, permits, and notifications—including those mandated by NEPA—as the project progresses. An initial review of environmental conditions is found in the FORGE *Environmental Information Synopsis* (Irving and Podgorney, 2016) and the environmental checklist attached to the FORGE *Environmental, Safety, and Health Plan* (Smith, et al., 2016). Results indicate NEPA requirements will be met within the required timeframe.

The following is a list of activities that have particular bearing for induced seismicity; also included is a general listing of the rules, laws, and codes that are relevant for the activities. These were identified from the Idaho Administrative Procedures Act (IDAPA); Battelle Energy Alliance, LLC, (BEA) requirements; *Guidance for Reclamation and Reuse of Municipal and Industrial Wastewater* (Idaho Department of Environmental Quality, 2007); City of Idaho Falls Code (CIFC); DOE's water right agreement with the Idaho Department of Water Resources (IDWR) (DOE-ID, 2004); and BEA agreements with IDWR (Street, 2001). Activities that have particular bearing for induced seismicity are:

- Conducting an environmental assessment (NEPA)
- Constructing or modifying potable water-production, monitoring, and observation wells (IDAPA, BEA, and Idaho Department of Environmental Quality [2007])
- Constructing or modifying injection wells (IDAPA, CIFC, and BEA)
- Operating, discharging to, or monitoring permitted Class V deep injection wells (IDAPA, BEA, and CIFC)
- Operating potable water, production, monitoring, and observation wells (IDAPA, DOE-ID [2004], and Street [2001])
- Decommissioning (or abandoning) potable water, production, monitoring, and observation wells (IDAPA)
- Permanently decommissioning injection wells (IDAPA).

2.2 Radius of Influence

The radius of influence, or the area of potential negative impact due to induced seismicity, depends on a number of factors, including the lateral extent of shaking, population density, and number of nearby structures. The FORGE site lies within a sparsely populated region, and the nearest population center (Table 1) is approximately 13 km (8 mi) from the FORGE site (Figure 2).

Table 1. Nearby population centers and distances from the proposed project area.

Population Center	Distance to Project Area
Arco	19 km (12 mi)
Atomic City	25 km (15 mi)
Blackfoot	73 km (45 mi)
Butte City	13 km (8 mi)
Fort Hall	79 km (53 mi)
Howe	25 km (15 mi)
Idaho Falls	85 km (53 mi)
Mud Lake	57 km (35 mi)

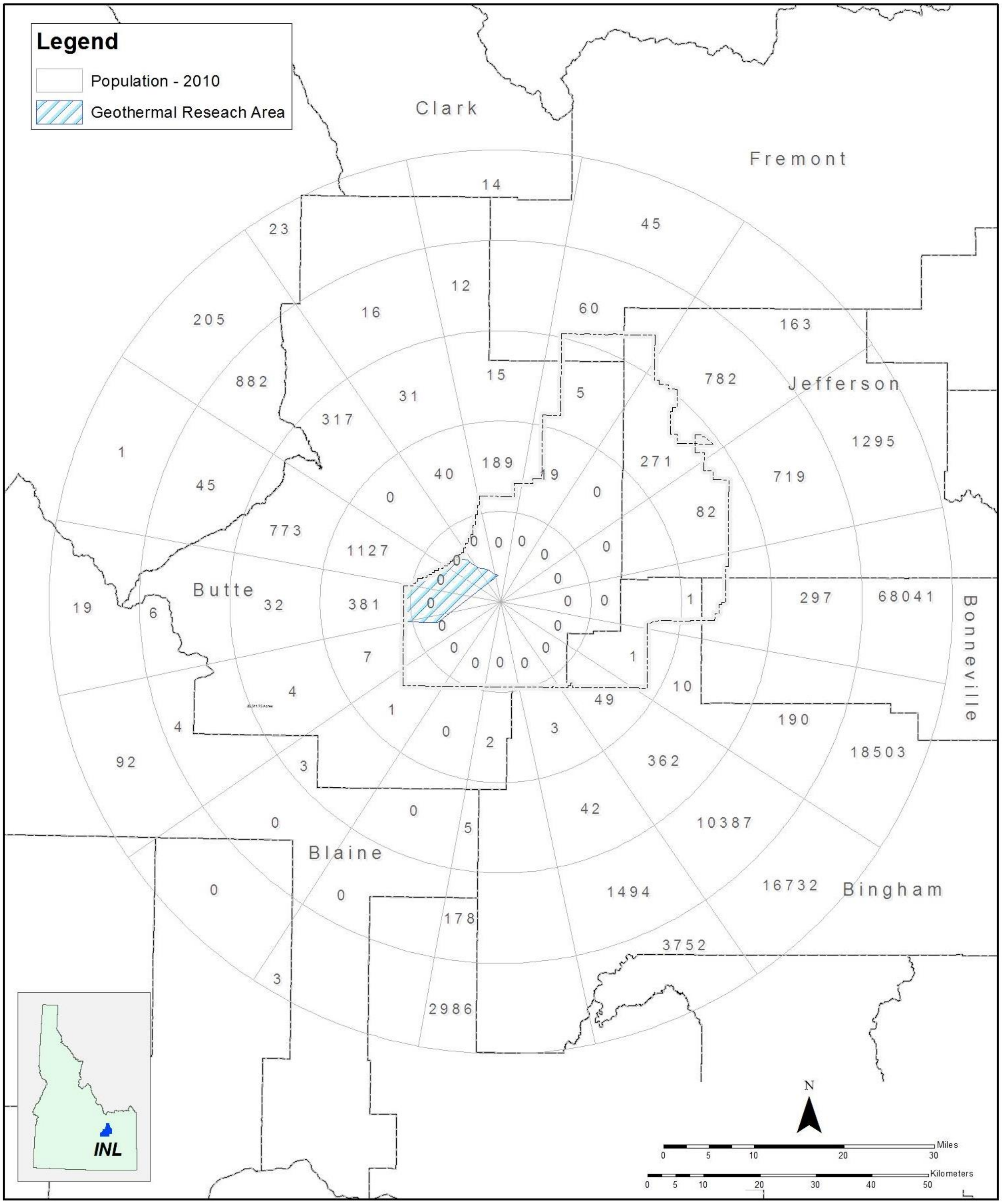


Figure 2. Map showing population from 2010 Census in each section surrounding the GRRA up to 80.5 km (50 mi) away (adapted from previous INL studies).

The expected lateral extent of shaking is controlled by the maximum injection-produced seismic event and the local ground-motion attenuation. Estimating the maximum likely earthquake is difficult, because it requires a detailed understanding of the physical process and exact subsurface geology and hydrology (Rubenstein and Mahani, 2015; Weingarten et al., 2015). Geothermal stimulations may also cause thermally induced events. In some cases, the maximum earthquake appears to scale with the volume of fluid injected or by the size of nearby faults, and local stress state may also play a role (McGarr et al., 2015). More sophisticated methods include estimates of fracture density (e.g., Shapiro et al., 2010) or the application of statistical models, but their usefulness as predictive models is unclear. It is clear that short-term injections, such as those associated with hydraulic stimulation or EGS, produce less seismicity than long-term injections typical of wastewater disposal.

An alternate approach, and the one suggested by Majer et al. (2012), is to evaluate magnitudes of earthquakes from comparable experiments in similar geological settings. In general, earthquakes in EGS tests are less than magnitude (M) 3.5, although larger events (e.g., M 3.4 at Basel, M 3.7 at Cooper Basin, and M4.7 at the Geysers) have occurred (Majer et al., 2014) (Table 2). Similar geology can be difficult to quantify, because all sites possess a unique mix of lithology and structure, but if sites in crystalline rock are omitted (e.g., Basel, Cooper Basin, Soultz-sous-Forets), the largest event appears to have occurred at the Newberry EGS site with a maximum moment magnitude (M_W) event of 2.6 (Foulger and Julian, 2013). Other sites in the western United States with volcanic or volcanoclastic lithologies in normal faulting settings (e.g., Bradys, Desert Peak, and Raft River) have upper limits on the order of M 2.5. Based on the comparison and allowing for variability in faulting, an estimate of the likely upper bound on magnitudes is in the range of M 3.5 to 3.8.

Table 2. Maximum magnitude earthquakes associated with EGS experiments.

Site	Magnitude	Geological Setting
Fenton Hill, NM	0.1	Granitodiorite
Hijori, Japan	0.3	Granite
Raft River, ID	1.1	Metamorphics
Desert Peak, NV	1.9	Faulted volcanoclastics
Bradys, NV	2.0	Faulted volcanoclastics
Ogachi, Japan	2.0	Granodiorite
Newberry, OR	2.6	Basalt/rhyolite
Soultz-sous-Forets, France	2.9	Granite
Basel, Switzerland	3.4	Crystalline
Cooper Basin, Australia	3.7	Granite

Ground-motion attenuation can be estimated by comparison with natural events. The United States Geologic Survey's "Did You Feel It?" archive of events in southern Idaho shows that events between M 2.5 and 3.0 typically generate Modified Mercalli Intensities between I (not felt, no damage) and III (weak shaking, no damage). Based on analogous experiments and a general maximum magnitude of M 3.5, we estimate that the radius of influence will be approximately 8 km (5 mi) away from the injection site (Figure 3). Further indications of relatively high regional ground-motion attenuation are provided by the fact that the 1983 M_W 6.9 Borah earthquake was located 89 to 110 km (55 to 68 mi) from INL facility areas, but no significant damage occurred (Gorman and Guenzler, 1983).

The seismic risk on the Eastern Snake River Plain (ESRP) has been studied extensively for decades because of activities at the INL Site. The SRP itself is seismically quiet and stable in contrast to the surrounding area, and there are no mapped faults at the surface within the GRRA (Kuntz et al., 1994). The GRRA is covered by basalt lava flows that are >519 ka (Kuntz et al., 1994). The primary geologic structures within the GRRA are two caldera boundaries (discussed in detail in Section 6, Seismic Hazard, and in the FORGE *Geological Conceptual Model* [St. Clair et al., 2016]).

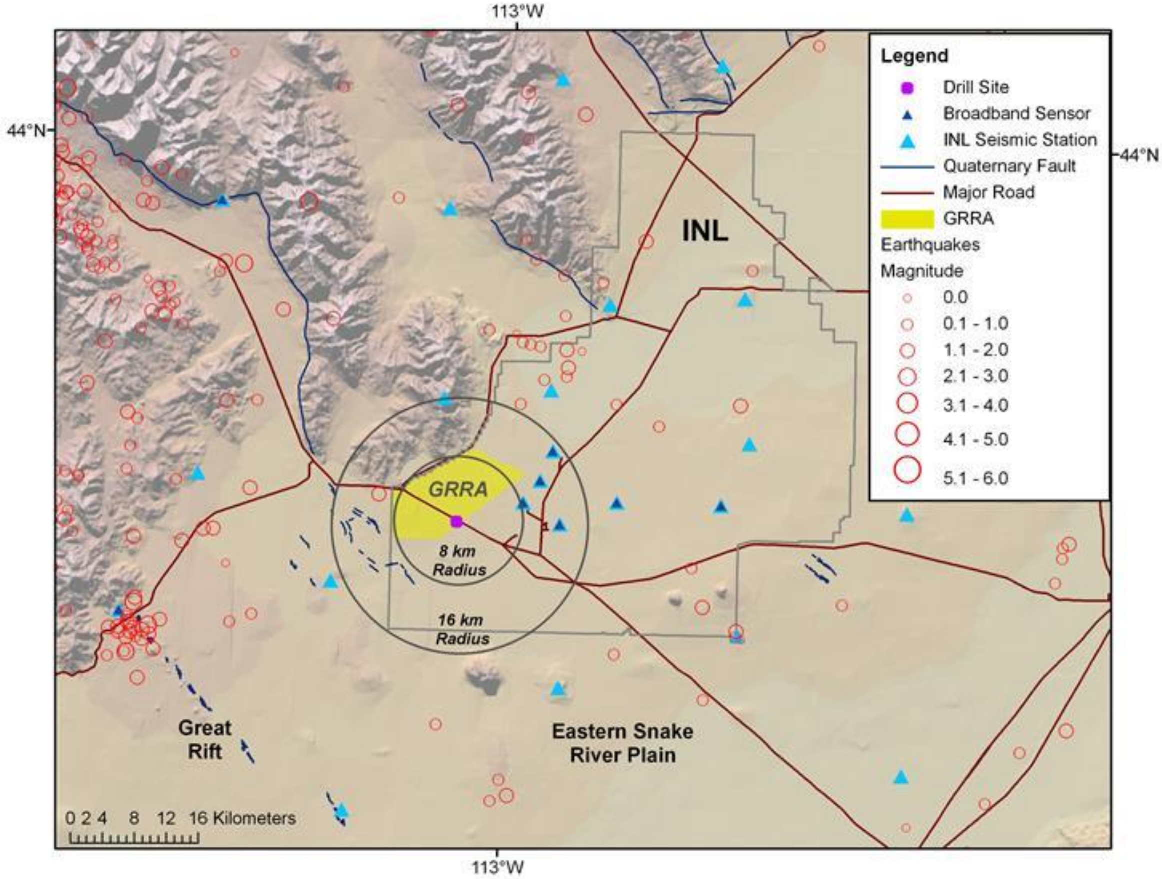


Figure 3. Map of INL Site, GRRA, major roads, seismic stations currently operated by the INL Seismic Monitoring Program, and earthquakes from 1972 to 2014 (INL Seismic Monitoring, 2016).

No seismic events have been recorded within the GRRA, and only two microearthquakes—with a duration magnitude (M_D) of 0.9 and 1.4—have been identified near the GRRA. An event in 1985 (M_D 0.9) was located north of the GRRA, and an event in 2001(M_D 1.4) was located west of the GRRA (Figure 3). Subsequent to these events, a 7-month microearthquake survey with 17 analog seismic stations spaced <2 km (<1 mi) apart was conducted in 1988 north of the GRRA (Jackson et al., 1989). Two microearthquakes (M_D <0.5) were detected by this temporary array, but they were located outside of the array and outside the GRRA.

In summary, the combination of low-magnitude expected seismicity, relatively high ground-motion attenuation, and sparse population suggests that the impact of injection-induced shaking is low. In comparison, shaking from natural events located in the region surrounding the SRP occurs periodically, so the population within the radius of influence is accustomed to seismic activity.

2.3 Potential Impacts

Potential impacts from induced seismicity range from physical damage caused by shaking to economic disruption caused by closures of buildings and facilities. This plan aims to minimize non-damaging, smaller-magnitude nuisance shaking due to EGS activities and to take steps to preclude larger induced seismic events that can cause damage.

The facilities closest to the FORGE EGS activities are on the INL site. The INL Site has seven facility areas, which are located in the south-central (five facilities), eastern (one facility), and northern (one facility) areas of the INL Site (Figure 4). INL Site facility areas are located 8 to 42 km (5 to 26 mi) from the FORGE drill site. Four facility areas have nuclear facilities with safety-significant structures, systems, and components; these facility areas are the Advanced Test Reactor (ATR), Idaho Nuclear and Engineering Technology Center (INTEC), Naval Reactors Facility (NRF), and Materials and Fuels Complex. The safety-significant structures, systems, and components are designed to withstand the impacts of ground motions from low-probability, large-magnitude earthquakes (earthquakes greater than M 6.7) that may occur on nearby Basin and Range faults (see Section 6.1.3). Additionally, ATR has a seismic shutdown subsystem to mitigate the impact of any larger seismic shaking on operations.

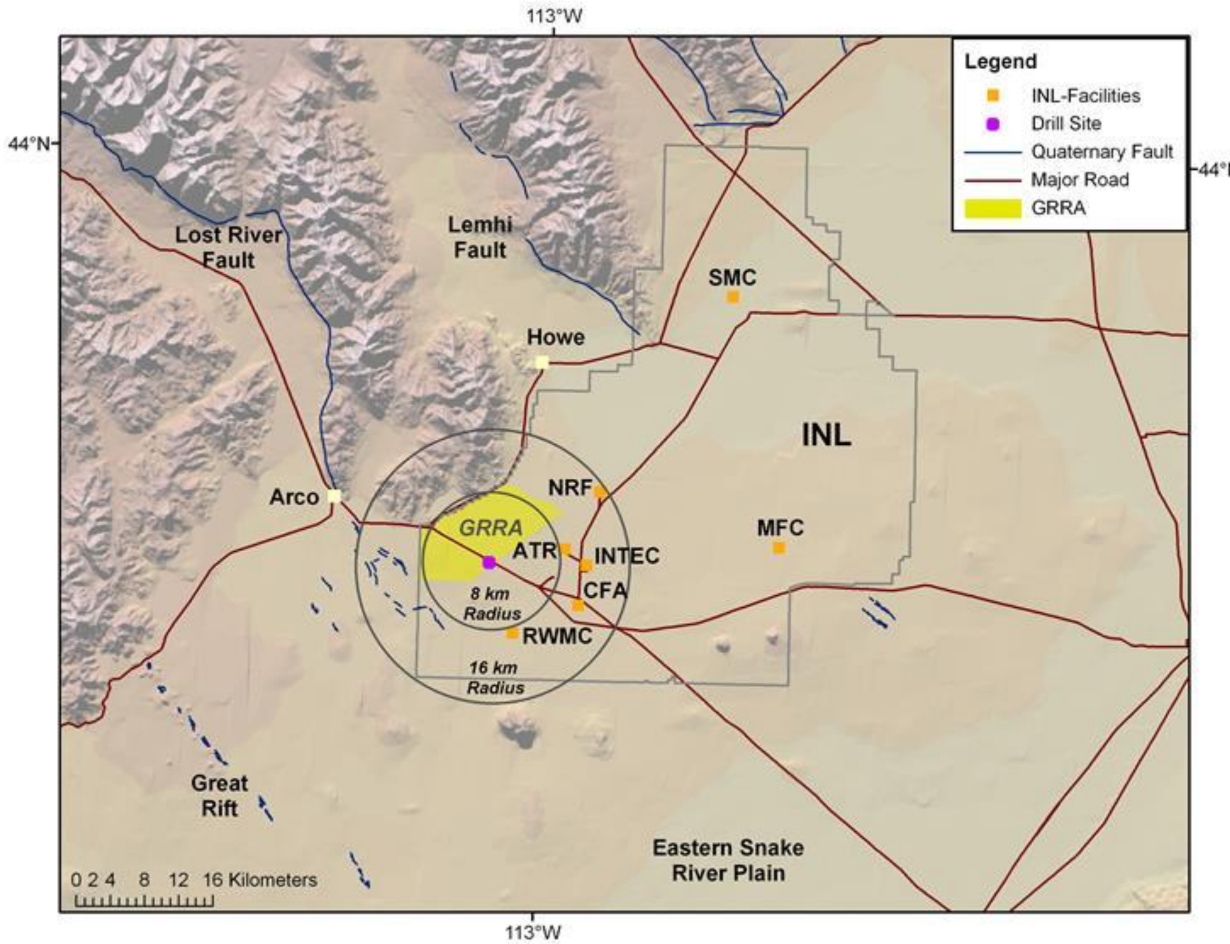


Figure 4. INL facility areas relative to the 8- and 16-km (5- and 10-mi) radii from the FORGE drilling site (ATR = Advanced Test Reactor, CFA = Central Facilities Area, INTEC = Idaho Nuclear and Engineering Technology Center, MFC = Materials and Fuels Complex, NRF = Naval Reactors Facility, RWMC = Radiological Waste Management Complex, SMC = Specific Manufacturing Capability).

More than 48 km (30 mi) to the east and south of the INL Site are four population centers (Idaho Falls, Pocatello, Rexburg, and Blackfoot) with more than 10,000 residents. Several other population centers with less than 10,000 residents, such as Arco, Howe, Mud Lake, Fort Hall Indian Reservation, and Atomic City, are situated within 80 km (50 mi) of the INL Site. Nearby visitor attractions include Craters of the Moon National Monument and Preserve located 26 km (16 mi) to the southwest of the INL Site and the Big Southern Butte National Natural Monument located 26 km (16 mi) to the south of the INL Site. We expect that any potential shaking from seismic events would only affect three population centers with less than 10,000 residents (Arco, Howe, and Butte City) and then only if the maximum magnitude event were to occur.

Our communications and outreach program (described in Section 3) has specifically targeted the communities within 80 km (50 mi) of the project so that the benefits and risks of the EGS project are clearly communicated to the residents of these cities. In general, the response to the project has been positive, as evidenced by the letters of support listed in Appendix A, Table A-2.

In terms of secondary hazards, the entire GRRA is a low-relief plain with little risk of landslides due to induced seismicity, owing to the flat nature of the landscape.

2.4 Approximate Lower and Upper Bound of Potential Damage

A detailed estimate will be made of the lower and upper bounds of potential damage in Phase 2, but community impact is low given the sparse population near the site. Operational facilities at the INL Site have been evaluated for moderate- to large-magnitude earthquakes and upgraded as necessary. Thus, the impact of damage from low-magnitude earthquakes is expected to be small.

2.5 Classification of Risk

To date, the response of local communities, regulators, and public officials to the project has been positive. Portions of our preliminary communications and outreach program (described in Section 3) are already in place to maintain and expand the current level of support among our stakeholders and the general public with regard to the FORGE project.

Based on the previous analyses (favorable regulatory environment, limited radius of influence, and low potential impacts), and considering the interactions with the local communities, we gauge the overall risk level to be low. We believe that we can proceed with the planning, but, as indicated above and in subsequent sections, we have identified specific additional analyses (e.g., refined radius of influence and estimates of potential damage) that are necessary in Phase 2 of the project to verify that the analyses are robust.

3. COMMUNICATIONS AND OUTREACH PROGRAM

Our communications and outreach program includes static, dynamic, and multi-directional components of information exchange between the SRGC and the local communities, regulatory agencies, and government stakeholders. Static components of the program disseminate general background information (e.g., a FORGE fact sheet) from the SRGC to interested stakeholders. Dynamic components of the program (e.g., a social media post) allow quick dissemination of information to local communities and other interested stakeholders. The multi-directional components of the program (e.g., a community meeting) provide forums for direct information exchange between stakeholders and the SRGC. To facilitate open dialogue with the public, the *Communications and Outreach Plan* (Ulrich and Podgorney, 2016) includes activities specifically geared to the three major FORGE phases—pre-stimulation (Phases 1 and 2), stimulation (Phase 3), and post-stimulation (Phase 3)—using all three modes of information exchange. If induced seismicity occurs, it will be during the stimulation period of the FORGE project. Therefore, the outreach schedule is designed accordingly.

3.1 FORGE Phases 1 and 2

To assess public response, beginning as early as 2012, project leadership organized briefings and outreach meetings between various members of the SRGC and key community, regulatory, and government stakeholders, including special interest groups (Appendix A, Table A-1). These multi-directional information exchanges resulted in letters of support from members of local communities, regulatory agencies, and government officials, indicating a strong level of acceptance at the state and local level for the project (Appendix A, Table A-2). Nearly all special interest groups in the regional area have neutral to positive interactions with INL. For technical information exchange, various members of the SRGC have presented, and are scheduled to present, research at professional meetings and events (Appendix A, Table A-3). Additionally, past and planned general meetings, tours, and events will enhance communications, education, and support in local communities (Appendix A, Table A-3). Figure 5 shows the local communities that are supportive of FORGE to date; no individual or group has opposed establishing FORGE on the INL Site.

The SRGC also aided in the creation of interactive technical displays for tours of the Center for Advanced Energy Studies (CAES), where SRGC is based, in Idaho Falls, Idaho. The project portion of the tour discusses FORGE and EGS in general and outlines how the project can benefit the local and national community. To further enhance communications with the public, we worked with various local and national media outlets that were covering stories about FORGE in general and the Idaho location in particular. We have also interfaced with the INL Public Relations Department to bring a feature story on the FORGE project to the official INL website and create a YouTube video (https://youtu.be/FiX7nHBrfzM) describing why the INL Site is an ideal location for the EGS experiment.

Static and dynamic components of information exchange have been created and implemented. Informational documents and flyers, such as fact sheets and media kits, have been developed and distributed to interested stakeholders and the media. Our official FORGE project website (snakerivergeothermal.org) was created and can accommodate both static and dynamic information outlets. Through the website, the public and other interested stakeholders can sign up to receive project emails. In Phase 2 and beyond, these will include the delivery of monthly e-newsletters that describe updates on the project, outreach activities, general facts about geothermal energy, and other pertinent information. Also, in Phase 2 of the project, the website will be upgraded to include a news page to give reporters and other media professionals a one-stop shop for the latest news, press releases, links to publications, live feeds of the social media outlets, and a reporters' guide. Currently, updates on social media sites have been accommodated through CAES and INL Facebook and Twitter feeds to leverage the thousands of followers of those accounts. In Phase 2 of the FORGE project, the communications and outreach team will assess this strategy and determine if dedicated project Facebook and Twitter accounts would be beneficial or if it makes more sense to continue leveraging CAES and INL accounts. The dedicated Twitter hashtag #SnakeRiverFORGE will continue to be used to help categorize social media posts and facilitate search results. These information components will be routinely updated throughout the duration of the project.

To increase community involvement at all levels, educational programs targeted to K-12 and higher education audiences are being created to increase awareness and appreciation among local youth of STEM (Science, Technology, Engineering, and Mathematics) research and opportunities in the community. A 1-day open house/EGS event is being planned for late summer 2016 that will focus on educating and improving stakeholder understanding of EGS projects in general and the FORGE project in particular. A media tour of the FORGE site during this same timeframe is also being organized to help disseminate background information to a wider audience.

In Phase 2 of the project and beyond, additional public meetings will be scheduled in nearby communities to discuss FORGE-related issues. This will be the ideal forum to discuss EGS in general and how the FORGE project will have the potential to directly and indirectly support local community needs and national energy needs. The risk of induced seismicity will be specifically discussed at the meeting, and concerns will be directly addressed.

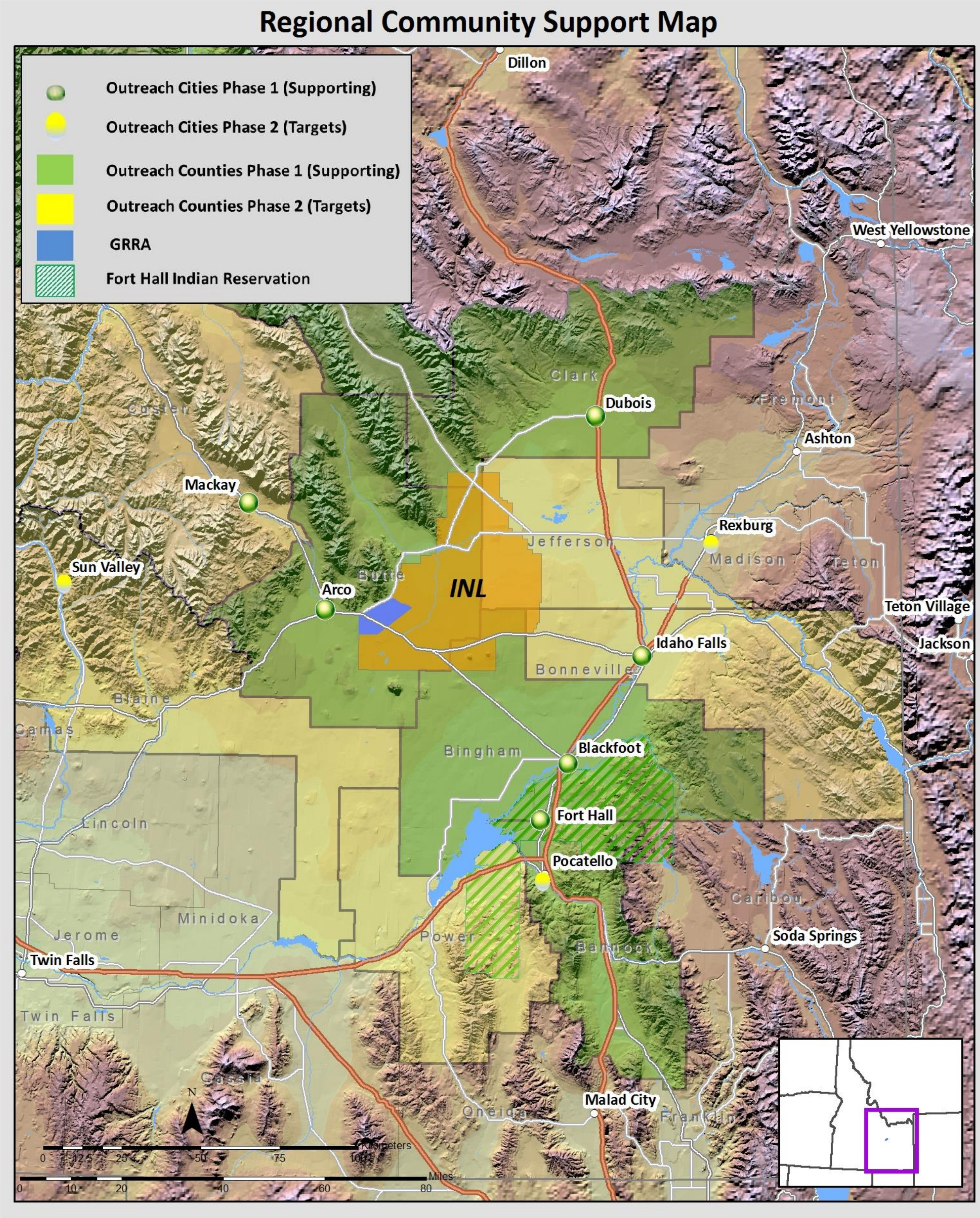


Figure 5. Cities and counties supportive of FORGE.

Assessment of the communications and outreach program will be ongoing. We will solicit feedback about the effectiveness of the program, and the communications lead will be actively engaged in updating the program, as needed, based on stakeholder input and assessment activities.

The pre-stimulation-stage activities are summarized as follows and described in more detail in the *Communications and Outreach Plan* (Ulrich and Podgorney, 2016):

- Meetings with community, regulatory, and government stakeholders, as well as special interest groups
- Meetings with INL nuclear facility operators and the lead for nuclear safety
- Presentation and publication of technical material at professional meetings and events
- Nontechnical meetings, tours, and events
- FORGE interactive technical displays at CAES
- Media interviews
- Informational documents: fact sheets, media kits, booklets
- Project website
- Project email subscriber list
- Weekly social media posts on Facebook and Twitter
- K-12 educational material
- Summer 2016 open house/EGS event
- Summer 2016 site tours for the media
- Initial community meetings.

3.2 FORGE Phase 3

Just prior to the initiation of the FORGE field season, community meetings in nearby cities will be scheduled to describe the stimulation procedure, the expected benefits, and the efforts to monitor and mitigate potential induced seismicity. The procedure for reporting "felt" seismic events will be described, as will the official procedure that will be used to handle the reports. At the meeting, feedback about the effectiveness of the current communications and outreach program will be solicited, and the communications lead will be actively engaged in updating the program, as needed.

During the stimulation stage, which may consist of a variety of individual stimulation procedures, stakeholder meetings will be conducted, as needed. Weekly updates will be provided via email to those on the project subscriber list, posted on social media, and displayed on the project website. Updates to the What's Happening and Director's Message sections of the homepage can quickly provide highly visual and targeted information, as necessary. Media interviews will also be scheduled to reinforce the public's understanding of the goals and benefits of the project, describe the stimulation procedure, and explain the risk of induced seismicity. Site tours for the media, the public, and other interested stakeholders will be conducted during the stimulation stage, as feasible.

The stimulation-stage activities are summarized as follows:

- Community meetings just prior to the initiation of the stimulation stage
- Stakeholder meetings, as necessary
- Monthly project email subscriber updates
- Weekly social media posts on Facebook and Twitter
- Monthly project updates on the official project website

- Media interviews
- Site tours for the media, the public, and other interested stakeholder groups, as feasible.

3.3 FORGE Phase 3 and Beyond

After the stimulation stage, community meetings at nearby cities will be planned in order to report on the results and outcomes of the stimulation. The next steps will be discussed, as will positive and any negative impacts associated with the project at the local, state, and national level. At the meetings, feedback about the effectiveness of the current communications and outreach program will be solicited, and the project communication lead will be actively engaged in incorporating community input into the program, as needed.

Additional stakeholder meetings, community meetings, and media events will be held, as appropriate, based on continuing operations at the site. Monthly updates will be provided via email to those on the project subscriber email list, posted to social media, and displayed on the project website. Technical information exchange will continue to be a priority, with various members of the SRGC expected to present research at professional meetings and events, as appropriate. Nontechnical meetings, tours, and events will continue to be planned in order to enhance communication, education, and support in local communities.

The post-stimulation-stage activities are summarized as follows:

- Community meetings to report on stimulation results and as needed thereafter
- Stakeholder meetings, as necessary
- Media interviews and events, as necessary
- Monthly project email updates
- Monthly social media posts on Facebook and Twitter
- Monthly project updates on the official project website
- Presentation and publication of technical material at professional meetings and events, as appropriate
- Nontechnical meetings, tours, and events, as appropriate.

4. GROUND VIBRATION AND NOISE

4.1 Review of Local Standards and Criteria

Relevant state and local regulations and ordinances related to noise and vibration disturbances have been reviewed. These include potential hydraulic fracturing regulations, potential building threshold cosmetic damage criteria (e.g., Siskind et al., 1980), potential construction vibration limits (e.g., CDT, 2013; FTA, 2006), potential ground-motion limits to avoid structural damage (e.g., Dowding, 1996; Siskind, 2000), potential human exposure to vibration (e.g., ANSI S2.71-1983; ISO 2003; Dowding, 1996). Given the expected plan, we anticipate no problems adhering to these regulations.

4.2 Assessment of Existing Conditions

4.2.1 Ground Vibration Noise Analysis

Ground noise and vibration have caused problems and complaints at previous EGS sites, such as Basel in Switzerland and the Geysers in California (Majer et al., 2014). Often, the levels of noise and vibrations do not reach the point of causing problems but can be perceived as an annoyance and nuisance to neighboring communities. The INL Site lies in a much more sparsely populated area than either Basel or the Geysers (Figure 1), and the nearest town is 13 km (8 mi) away from the FORGE site. Some INL facilities are slightly closer (8 km [5 mi]) to the FORGE site, but these have been designed for seismic safety. Therefore, the overall impact seems likely to be low. In the following section, a preliminary assessment of local conditions is provided, and it will be expanded upon in Phase 2, with additional noise monitoring, review of potential vulnerable facilities, and consistency with local regulations.

To assess existing conditions (Majer et al., 2012) and establish a baseline value, continuously recorded data at two seismic stations near the GRRA are used to assess ambient ground vibration noise levels. The two stations are INLF and NVRF (Figure 6). NVRF is located near NRF and cultural noise sources such as buildings, roads, and parking lots. INLF is located ~4 km (~2.5 mi) to the south and away from major facilities. The results of the seismic ambient noise analysis at these two stations are expected to represent typical maximum ambient noise ground vibration levels in and around the GRRA. The seismic instruments are both Nanometrics Trillium 120PA broadband seismometers. The frequency response of the instruments shows a flat response from low frequencies (~0.01 Hz) to higher frequencies (~30 Hz). Data from the seismometers are recorded using Quanterra Q330 data loggers. Each station consists of a concrete vault at the ground surface on basalt rock. The vault houses the broadband seismometer, a strong-motion accelerometer, and the data logger. The instrument vault is capped and buried, which provides a stable temperature environment and protection from the elements and wildlife.

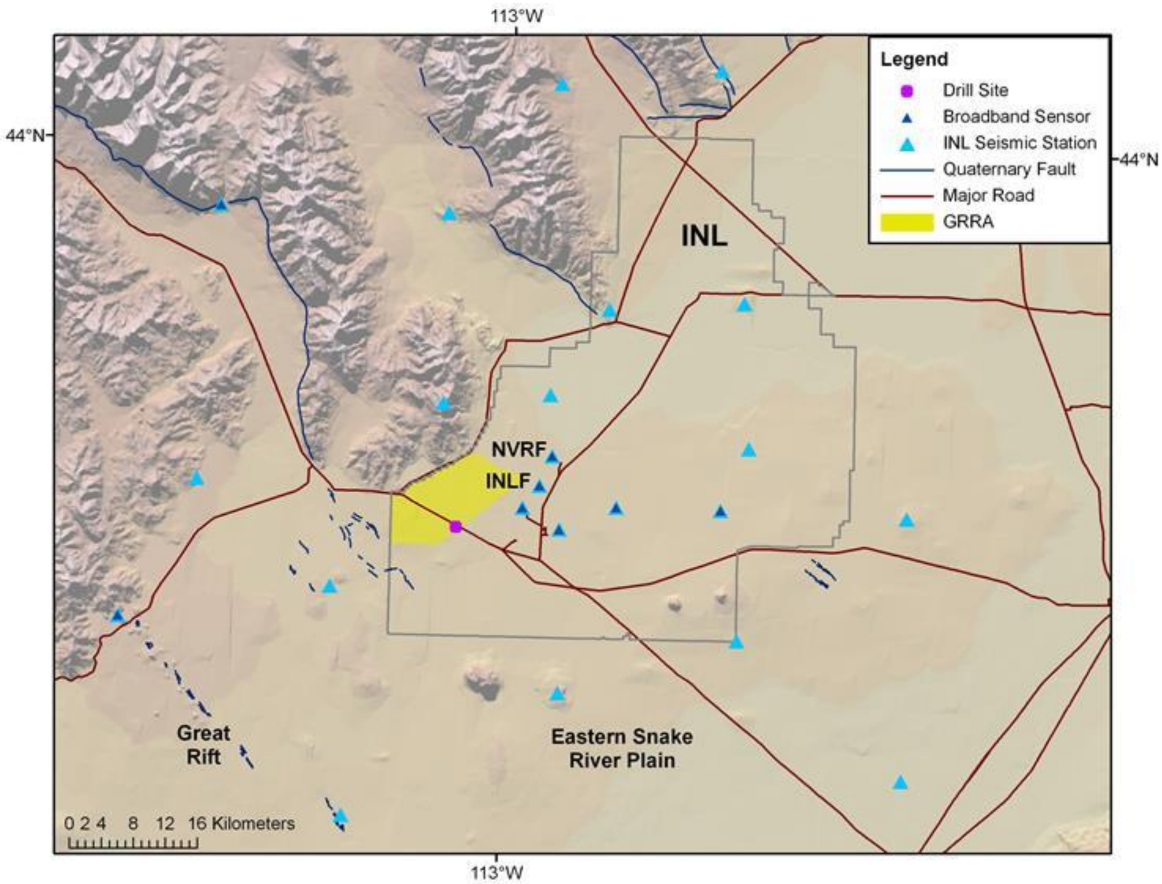


Figure 6. Map of the INL Site, GRRA, proposed drill site, and seismic stations operated by the INL Seismic Monitoring Program. NVRF and INLF are used for the ambient noise analysis.

The data loggers have been recording continuous data since May 2014. For the noise analysis, continuous data from May 2014 to November 2015 were manually retrieved. Each station recorded data at 100 samples per second from three components: two horizontal components oriented north-south (designated as HHN) and east-west (designated as HHE) and one component oriented vertically (HHZ).The noise analysis was conducted for the HHZ components at INLF and NVRF. The continuous data from the two broadband stations were analyzed using the method outlined in McNamara and Buland (2004). A probability density function (PDF) constructed from thousands of individual spectral estimates is used to quantify seismic noise. This type of analysis provides useful information to characterize the background noise levels for any broadband seismic station.

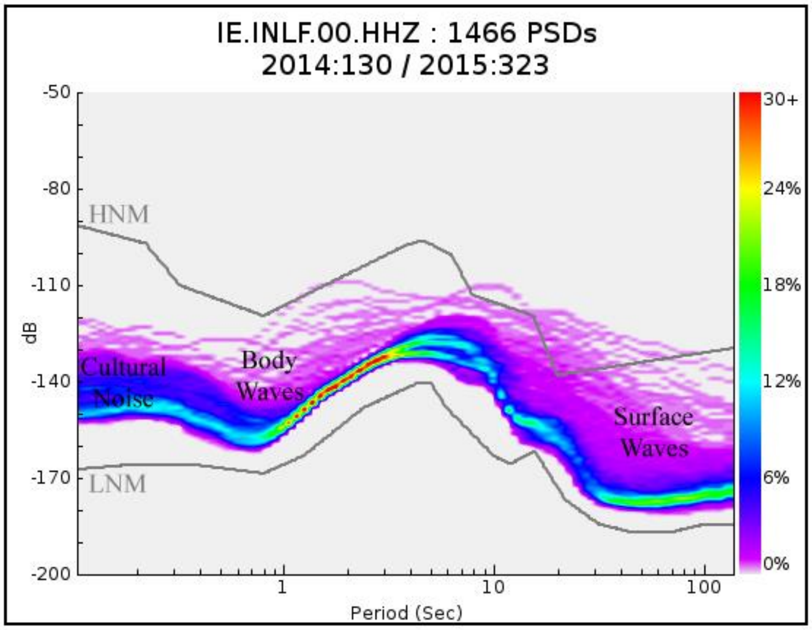
Figure 7 shows the PDFs for INLF and NVRF. Overall, INLF (Figure 7a) is much quieter than NVRF (Figure 7b). This is to be expected, because NVRF is close to an operational facility, and INLF is a few kilometers away from any active facility. Additional tools that can be used to provide insight into site-specific noise levels are diurnal plots of the noise levels at each station. Figure 8 shows the diurnal variations of INLF and NVRF. The diurnal plots show how much quieter INLF (Figure 8a) is compared to NVRF (Figure 8b). Both stations show a high noise level in the period range of 2 to 12 seconds uniformly throughout the 24-hour time span.

The cultural noises seen on the two diurnal plots for the time span between 5 a.m. and 5 p.m. local time are of particular interest. INLF is close to a major INL road but not near an active facility. Figure 8a shows distinct times of heavy vehicle traffic at the beginning and end of the work day, with spotty patterns indicating times of lighter vehicle traffic. In Figure 8b, NVRF shows a slight increase in cultural noise caused by the INL work day, but, because of NVRF's close proximity to an active INL facility, high-frequency noise can be seen throughout the day (solid red) and obscures the transient signal.

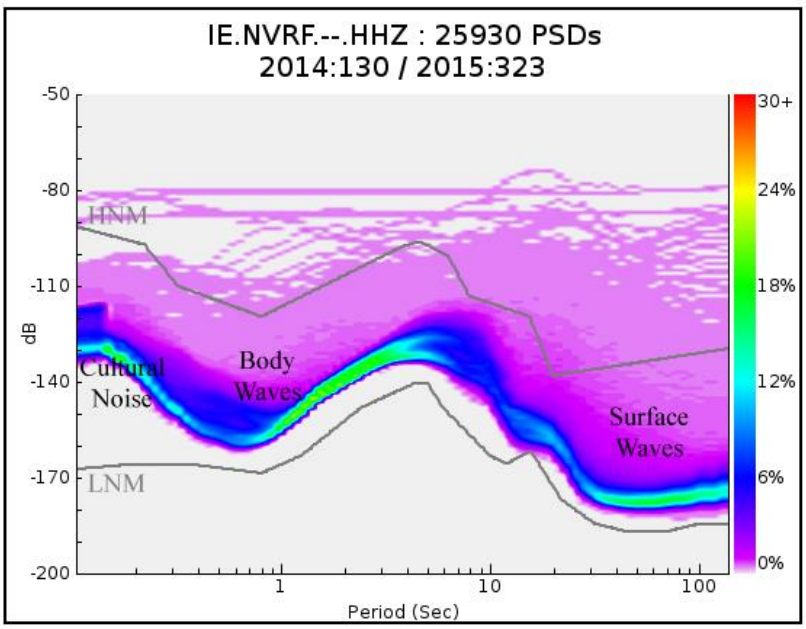
It is apparent from the PDFs and the diurnal plots that seismic stations near operational INL Site facilities measure higher noise levels throughout the day than a station located away from operations but near a road. INLF may be more representative of noise levels that may occur in and around the FORGE drill site. The hours from 5 a.m. to 5 p.m. local time at INLF provide a good estimate of the overall noise levels expected at the FORGE drill site (Figure 8a). These levels are fairly low (not far above the low-noise model shown in Figure 7a) and will allow low-threshold monitoring.

4.2.2 Aboveground Noise Analysis

A baseline aboveground noise analysis will be conducted in Phase 2 at the FORGE site. This can later be compared to noise present during operational activities.

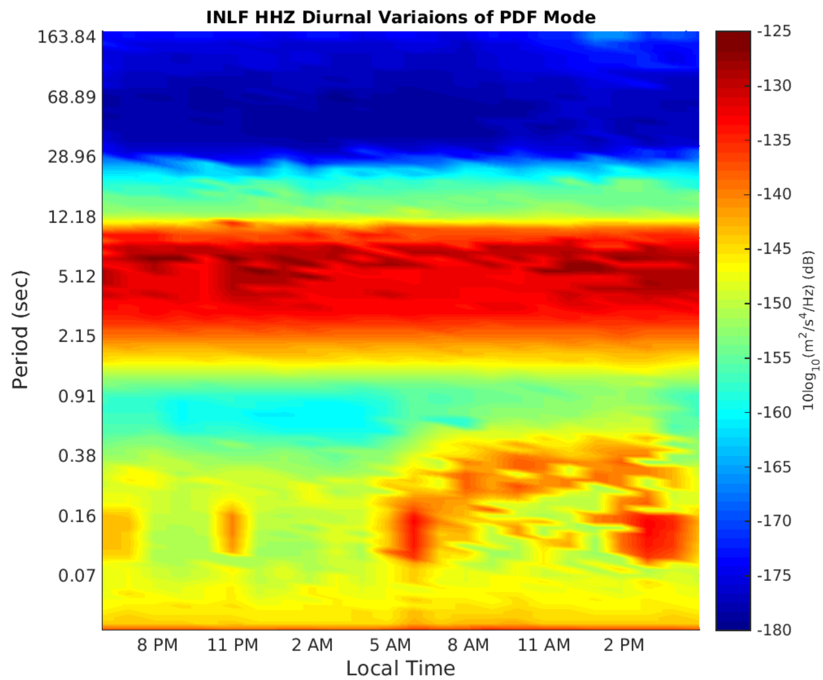


(a)

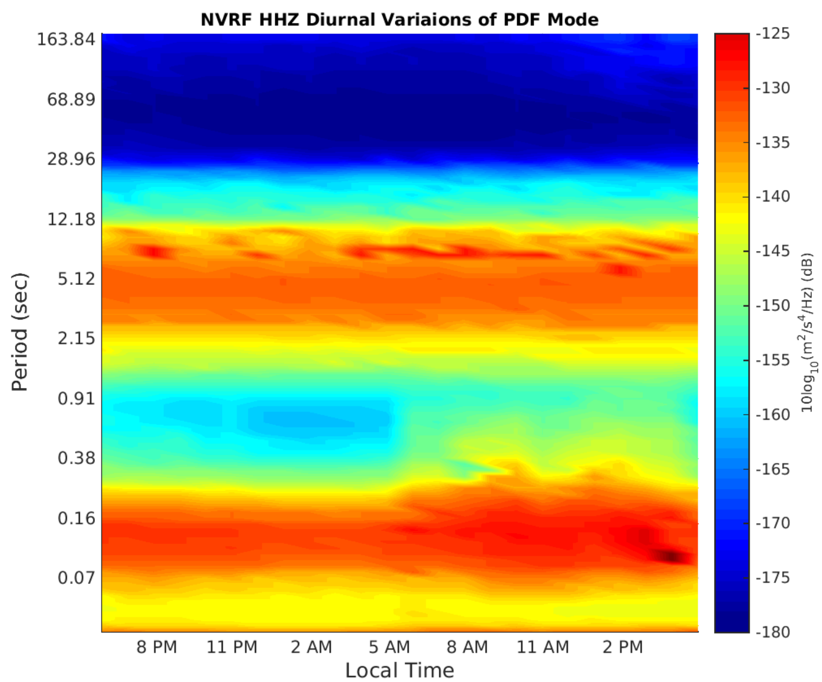


(b)

Figure 7. PDFs between 0 and 30% for (a) INLF showing lower seismic noise levels due to its greater distance from operational facilities and (b) NVRF showing higher noise levels due to its proximity to operational facilities.



(a)



(b)

Figure 8. Diurnal variation of seismic noise levels for (a) INLF and (b) NVRF. Noise levels are higher (more red) during working hours from 5 a.m. to 5 p.m. local time.

5. SEISMIC MONITORING

5.1 Existing Seismic Network and Observed Background Seismicity

Local seismic monitoring is necessary to establish baseline seismic rates prior to EGS activities and to monitor seismic events during and after stimulation. The desired minimum goal for baseline seismicity is a threshold detection level of M 1.0 (ideally M 0.0) with excellent location accuracy. Absolute locations accuracy should be able to resolve events at twice the radius of the stimulated volume at the depth of the expected reservoir. Application of relative location techniques should be able to improve the locations to image-discrete features. The FORGE site is already exceedingly well-covered by an existing high-resolution local seismic network that matches the required specifications and possesses an extensive and well-reviewed catalog. This network will be supplemented by additional stations in Phase 2.

Since 1972, INL has supported a program to monitor earthquake activity within INL Site boundaries, within the greater ESRP region, and within the surrounding Basin and Range Province. The existing INL Seismic Monitoring Program provides earthquake data and staff to support continuous monitoring of earthquake activity. The program hardware includes short-period seismometers, broadband seismometers, strong-motion accelerometers, and Global Positioning System (GPS) receivers.

Specifically, the INL Seismic Monitoring Program currently operates 33 permanent digital short-period and broadband seismic stations to determine the time, location, and size of earthquakes in the vicinity of the INL Site (Figure 9). Within the INL Site boundaries, the network has an average station spacing of 20 km (12 mi). Seven seismic stations surround the GRRA, and five are located within 16 km (10 mi) of the FORGE drill site (Figures 3 and 9). GPS receivers are also collocated at 17 seismic stations to determine rates of crustal deformation and locations of active seismic regions. One GPS receiver is located at a seismic station that is within 16 km (10 mi) of the FORGE drill site (Figures 3 and 9). Additionally, seismic data from up to 50 seismic stations from other nearby seismic networks are also monitored and available to improve the ability to accurately ascertain earthquake locations in and near the INL Site (Figure 9).

The stations in the INL seismic network are a mix of borehole and surface seismic stations that are located within approximately 161 km (100 mi) of the INL Site (Payne et al., 2014) (Figure 9). The seismic network is composed of one- and three-component seismic stations. Single-component, short-period seismic stations have vertically oriented velocity sensors (or seismometers) that are Mark Products Model L-4C, Teledyne Geotech Model S-13, or Teledyne Geotech Model S-13 Jr. seismometers. All seismic stations within the ESRP have their vertical-component seismometer located at the bottom of boreholes up to 20 m (65 ft) deep to help dampen wind and cultural noise. Seismometers at stations outside of the ESRP are buried within 3 m (9 ft) of the ground surface. Seismic stations with horizontally oriented velocity sensors have two Teledyne Geotech Model S-13 seismometers located within a concrete vault, in addition to the vertically oriented sensor. Nine stations have three-component Nanometrics Trillium 120PA broadband seismometers that are located on rock in temperature-controlled vaults. Digital radios, Internet, or Digital Subscriber Line links transmit data from the INL seismic stations to the INL Research Center at the Research and Education campus in Idaho Falls, Idaho. The network was designed to monitor both the relatively seismically inactive ESRP region, in which the INL Site is located, and the more seismically active range-bounding normal faults that surround the SRP (Figures 9 and 10).

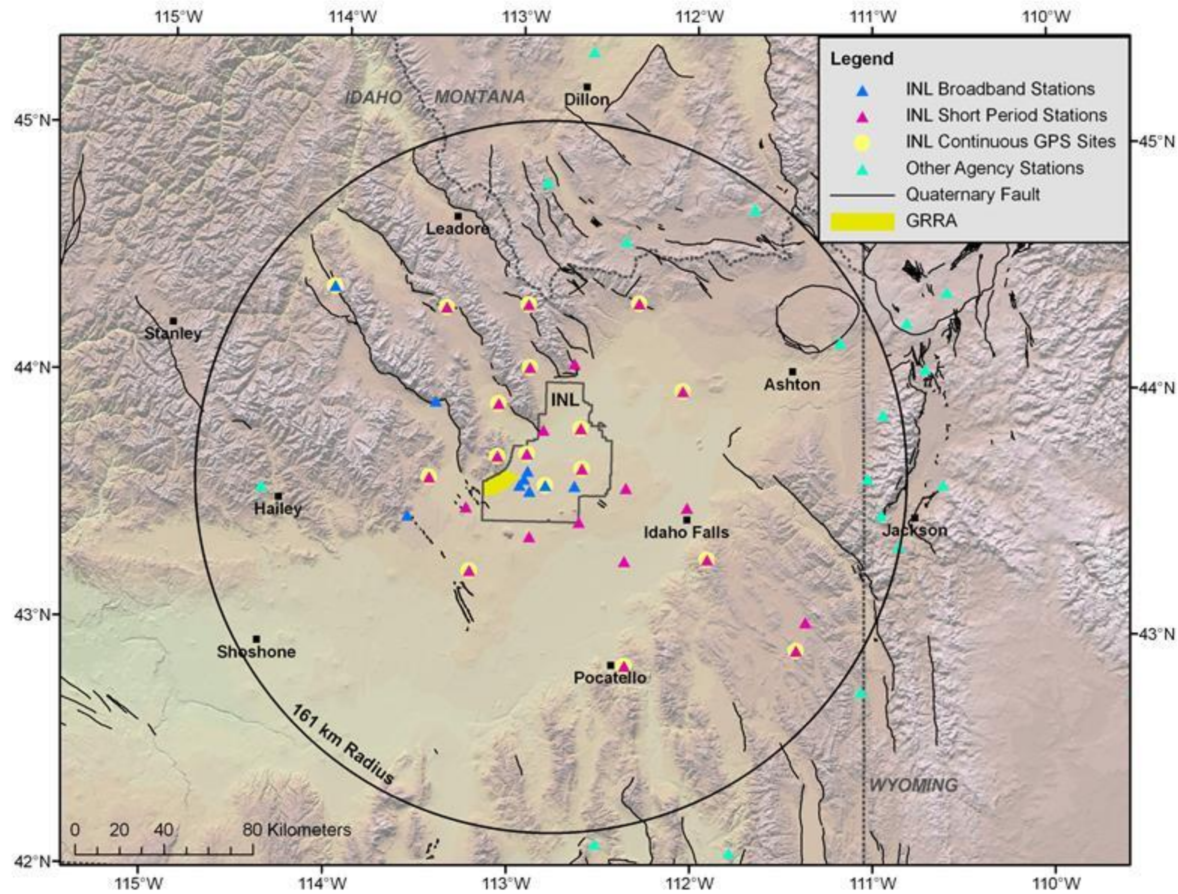


Figure 9. Locations of INL seismic stations, INL continuous GPS sites, and seismic stations monitored by INL that are operated by other institutions. Also shown are the 161-km (100-mi) radius around the INL Site for which INL reports earthquake locations, the relatively flat ESRP region, and nearby Quaternary faults.

The detection threshold of a seismic network can provide a measure of the completeness of the earthquake catalog. The detection threshold is defined as the magnitude level at which the seismic network will nearly always detect and locate an earthquake. In its current configuration, the INL seismic network has a detection threshold of ~M 0.2 within the INL Site boundaries. Microearthquakes from M 0.0 to M 2.0 are usually recorded at sufficient stations to permit accurate locations. For routine monitoring of earthquakes, a minimum of six seismic phase arrival times (P and S waves combined) are desired to attain relatively stable locations. The microearthquakes within the INL Site boundaries have from 6 to 26 phases, where M 0.0 events have the minimum number of phases. Locations of the INL microearthquakes have errors from ±300 to ±800 m (±984 to ±2,624 ft) horizontally and ±400 to ±2,000 m (±1,312 ft to ±1.2 mi) vertically (INL Seismic Monitoring, 2016).

The INL Seismic Monitoring Program also operates an additional 33 three-component accelerometers for the purpose of recording strong ground motions from large-magnitude, lower-probability local and regional earthquakes. Eight of the accelerometers are located within INL buildings to determine the response of these buildings to ground motions in the event of a large earthquake. Eleven of the accelerometers are located at free-field sites (i.e., not within buildings) near INL facilities or are collocated with seismic stations. The free-field data are used to determine the levels of earthquake ground motions at the ground surface and to assess ground-motion model parameters. Accelerometers are also located at 14 INL seismic stations whose data, which, along with data from some free-field sites, are transmitted via digital telemetry. Data from other accelerometers at some free-field sites and data from those within buildings are recorded on data loggers, which, when triggered, are then manually downloaded.

INL has recorded far-field ground motions from earthquakes within and outside the ESRP. Figure 10 shows that the majority of earthquakes occurring from 1972 to 2014 within 161 km (100 mi) of the INL Site were located in the Basin and Range Province regions surrounding the relatively stable ESRP region. During this time period, more than 80 microearthquakes, all of which had magnitudes less than 2.5, occurred within the ESRP. This suggests that the ESRP is relatively seismically inactive when compared to the surrounding Basin and Range Province (Jackson et al., 1993; INL Seismic Monitoring, 2016).

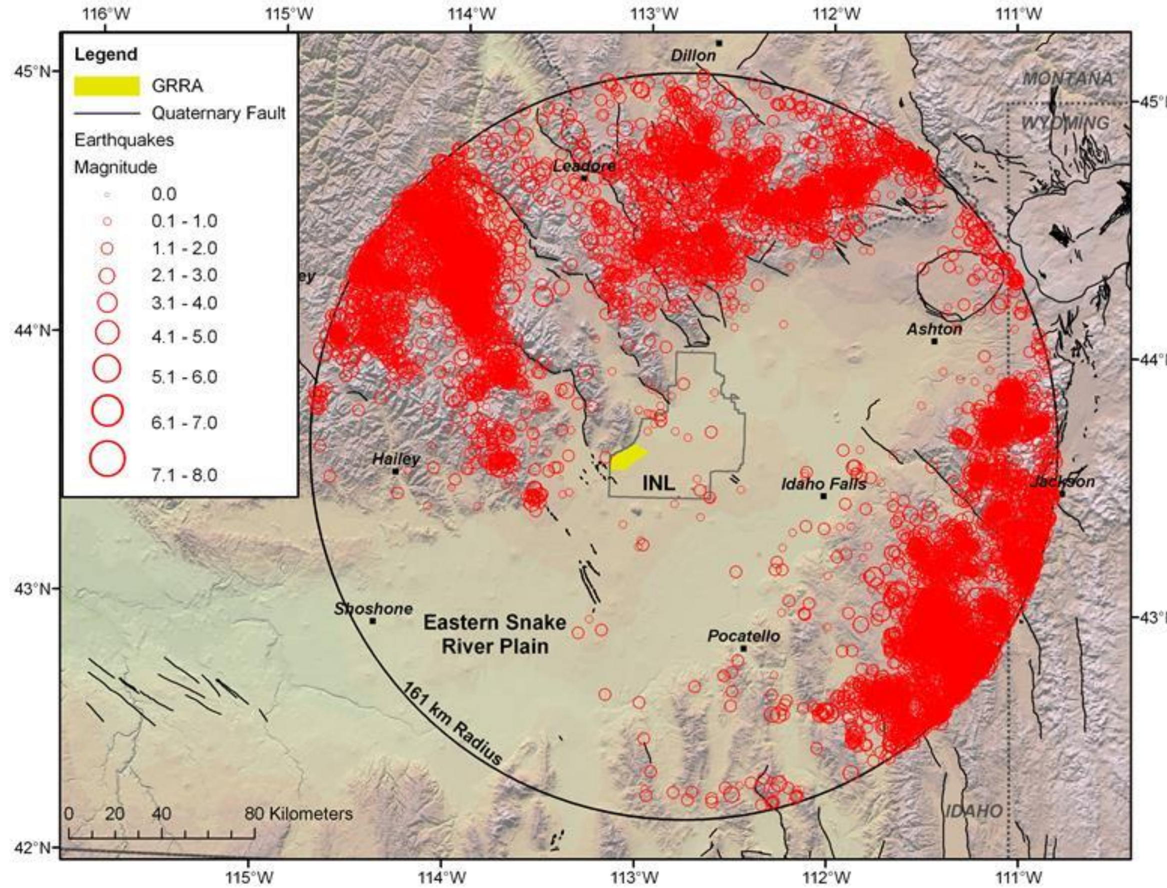


Figure 10. Map of epicenters of earthquakes from 1972 to 2014 within a 161-km (100-mi) radius around the INL Site (INL Seismic Monitoring, 2016).

5.2 Proposed Augmented Seismic Array

Currently, INL seismic stations within the INL Site are capable of detecting earthquakes on the order of M 0.2. Based on the ambient seismic noise evaluation in Section 4, broadband stations located near INL facility areas will have higher noise levels that may make it difficult to pick first arrivals of very small-magnitude earthquakes induced by operations in the GRRA. To accurately locate induced seismicity with very small magnitudes, a dense local seismic network close to the drilling site will be needed. INL seismic stations located away from facility areas on the INL Site and others remotely located in nearby mountainous areas may have low enough noise levels to detect small events near the drilling site and could be used to supplement the dense local network near that site.

Baseline background seismicity at and near the FORGE drill site will be established using an array of temporary seismic stations. Eight temporary surface seismic stations will be installed during Phase 2 to cover an area with a 4-km (2.5-mi) radius to permit a detection threshold of near M 0.0 at depths between 2 and 4 km (1.2 to 2.5 mi) (Figure 11). The close station spacing of the temporary array is designed to detect any M 0.0 events at the FORGE drill site that may currently be undetectable by INL permanent stations. The temporary seismic stations will be installed along existing roads to allow easy access and minimize cultural and ecological disturbances. The seismic instrumentation will include three-component short-period seismometers, digital data loggers, and cell-phone modem telemetry for real-time monitoring. Nearby INL permanent seismic stations will be used to supplement the detection and location of any small-magnitude earthquakes occurring near the FORGE drill site.

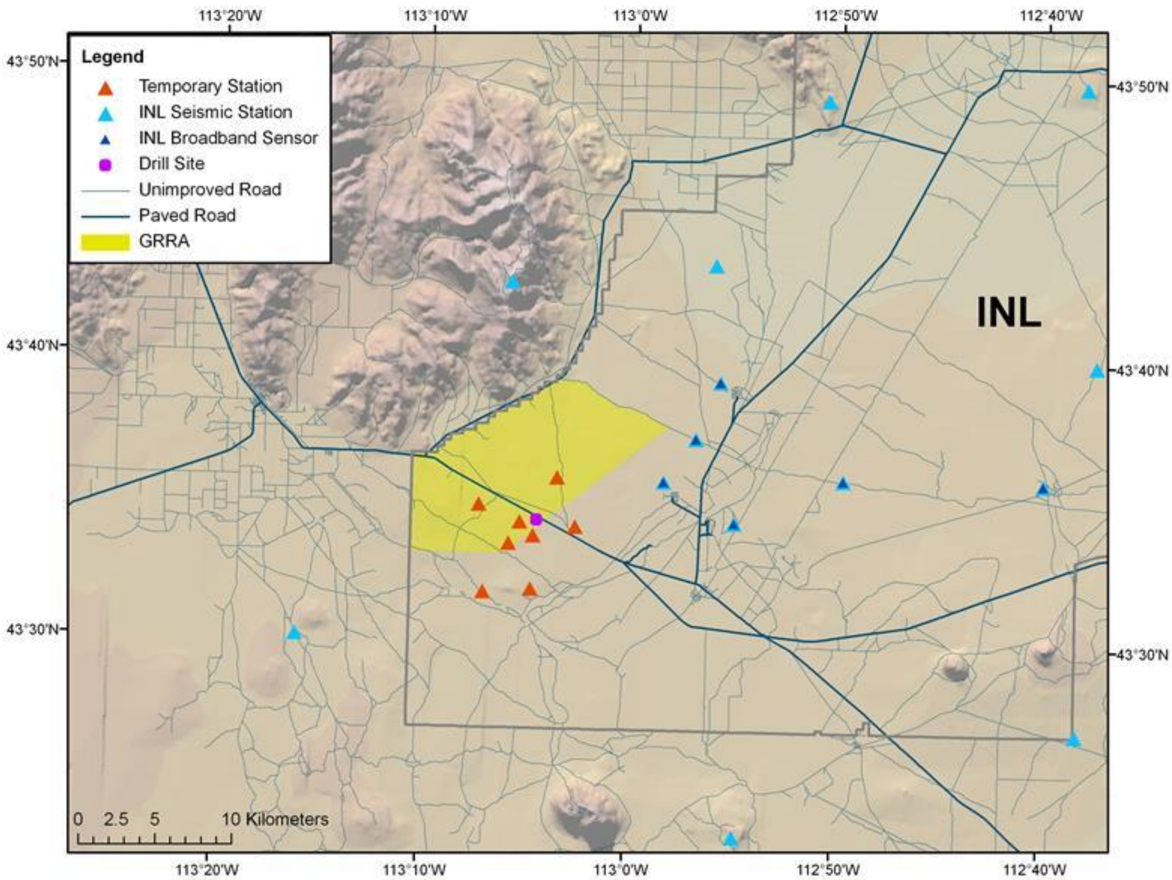


Figure 11. Proposed locations of temporary surface seismic stations (orange triangles) and nearby existing INL permanent seismic stations (blue triangles). Three temporary stations are south of the FORGE drill site and located over the proposed stimulation area.

Seismic data from temporary seismic stations will also be used to assess baseline ambient noise prior to FORGE stimulation activities and will become permanent seismic stations later in Phase 2. The permanent local seismic network will be configured for detecting M 0.0 or smaller earthquakes and delineating hypocenters with vertical control to map vertical fractures during stimulation activities. Stimulation activities will involve horizontal drilling and stimulation of vertical fractures likely aligned with northwest-southeast orientations over an area of 1,500 × 600 m (4,921 × 1,968 ft). To cover this area and provide depth control, the FORGE permanent network will consist of eight to 10 stations with three-component, short-period sensors. At least five stations will have their sensors in boreholes and will be located at the perimeter of the stimulation area, depending on results of the ambient noise analysis from the temporary stations. It is proposed that borehole sensors be placed at the top of rhyolite if depths are less than 457 m (1,500 ft). Sensors located at the top of rhyolite will have clear seismic-phase arrivals to improve hypocenter locations and will avoid travel paths through the sedimentary interbedded basalts above, which tend to degrade seismic signals due to velocity reversals. Three to five other stations will be located at the surface and within 4 km (2.5 mi) of the stimulation area to locate potential earthquakes occurring outside the stimulation area. The final configuration of station locations will be determined by analyzing seismic station geometry to assess the best configuration to minimize hypocentral errors.

The INL Seismic Monitoring Program will also install a new station with three-component broadband and acceleration sensors within 2 km (1.2 mi) of the FORGE stimulation area. The station will be installed to provide an assessment of ambient background noise prior to drilling activities and, in the event of any naturally occurring or manmade larger-magnitude earthquakes, waveforms for earthquake source analysis and accelerations. The INL Seismic Monitoring Program is a resource for earthquake information to INL facility managers in the event of earthquakes that cause ground shaking.

Earthquake data from the FORGE seismic stations will be telemetered via cell phone modem or digital radio to CAES in Idaho Falls. INL seismic stations needed to supplement the FORGE local network will be provided through the intranet to the FORGE data-acquisition and analysis system also located at CAES.

5.3 Seismic Data Processing and Monitoring Reports

We will perform near real-time seismic data processing and analysis of the digital seismograms to determine the location, magnitude, and peak ground acceleration (PGA) of any earthquake that may occur at the FORGE site. Seismic data-processing software will automatically detect, locate, and determine the magnitude of triggered events during FORGE activities. A variety of packages are available ranging from open-source to commercial; a decision on the exact package will be made in Phase 2. A preference is for an open-source package, because incorporation of auxiliary processing modules and improvements will be easier. Source mechanisms will be estimated when possible. Arrival times of seismic phases and amplitudes of the observed waveforms will be subsequently verified and archived.

Currently, the INL ESRP velocity model is used to locate earthquakes that occur near or within INL Site boundaries. This model was developed from Sparlin et al. (1982) and Braile et al. (1982) and checked by Jackson et al. (1989). Improvements to the velocity model are expected with our Phase 2 studies using ambient noise correlation.

During stimulation, seismologists will be available to verify the automatic processing and to characterize (e.g., location, source mechanism) the events occurring within and near the stimulation zone. Our staff technicians will also be available to quickly and safely resolve any seismic network hardware or software problems. Data will be transmitted to the data dashboard on our website for accessibility by other collaborators and project managers in accordance with the FORGE *Data Dissemination and Intellectual Property Plan* (Weers and Podgorney, 2016).

During periods of stimulation, the data dashboard and associated automated reports will be updated in near real time. The dashboard and reports will include summaries and graphics of event hypocenters and ancillary information (source mechanisms, b values, etc). Operational information on network status (triggers, metrics of seismic data for quality control, and instruments parameters such as battery voltage and telemetry status) will also be included. Off-the-shelf software will be used to the extent possible for analysis. Close coordination between the seismologists and engineers to compare injection parameters with observed seismicity is planned.

A procedural response (including predefined mitigation) will be defined for outlier events, i.e., events that exceed a specified magnitude threshold, peak ground acceleration, or distance from the injection zone. For example, thresholds might be defined as events larger than M 2 or more than 1 km (0.6 mi) from the stimulation zone. Other unusual patterns of seismicity may also be defined as outliers. The thresholds and responses will be further defined in Phase 2 but would likely include immediate notification of the FORGE operations center and key personnel. Depending on predefined severity, the FORGE operations center would notify other agencies as needed (e.g., INL emergency management, local government, and DOE).

Monitoring will continue during long-term post-stimulation but at lower operational level.

6. SEISMIC HAZARD FROM NATURAL AND INDUCED SEISMIC EVENTS

6.1 Hazard from Natural Seismicity

6.1.1 Seismotectonic Setting

Baseline natural seismic hazards at the GRRA can be of either tectonic or volcanic origin. The GRRA is located in the ESRP, which is a low-relief region covered by basaltic lava flows and sediments as described in *Conceptual Geologic Model* (St. Claire, et al, 2016). It transects and sharply contrasts with the surrounding mountainous country of the Basin and Range and Yellowstone Plateau (Figure 12). The ESRP represents the northeast-trending track of the Yellowstone hotspot that encompasses silicic volcanic centers that were active millions of years ago from 12.5 to 4.6 Ma (e.g., Anders et al., 2014). At the position of each active center, mafic crustal intrusions produced large-volume silicic eruptions that were subsequently covered by basaltic volcanism.

The ESRP is bordered by Basin and Range regions of the Centennial Tectonic Belt to the northwest and the Intermountain Seismic Belt to the southeast (Figure 12). These belts are zones of tectonic extension beginning ~16 Ma and continuing to the present day with active normal faulting and high seismicity (Rogers et al., 2002).

In the vicinity of the INL Site, silicic volcanic centers were active from 6.3 to 9.5 Ma (Figure 12). Caldera boundaries may represent locations for arcuate normal faults (or ring faults) that were active during silicic volcanism but are now buried by basalt flows and sediments. The positions of the interpreted caldera boundaries are based on the evaluation of drill cores and silicic rocks along the margins of the ESRP. The boundaries may be 5 to 6 km (3.1 to 3.7 mi) wide, representing multiple ring faults (e.g., Branney, 1995) around one caldera or nested calderas such as proposed for the two calderas intersecting the GRRA. The caldera normal faults could be present at 2- to 4-km (1.2- to 2.5-mi) depths and, taking into consideration the uncertainties, could be present anywhere within the GRRA (McCurry et al., 2016).

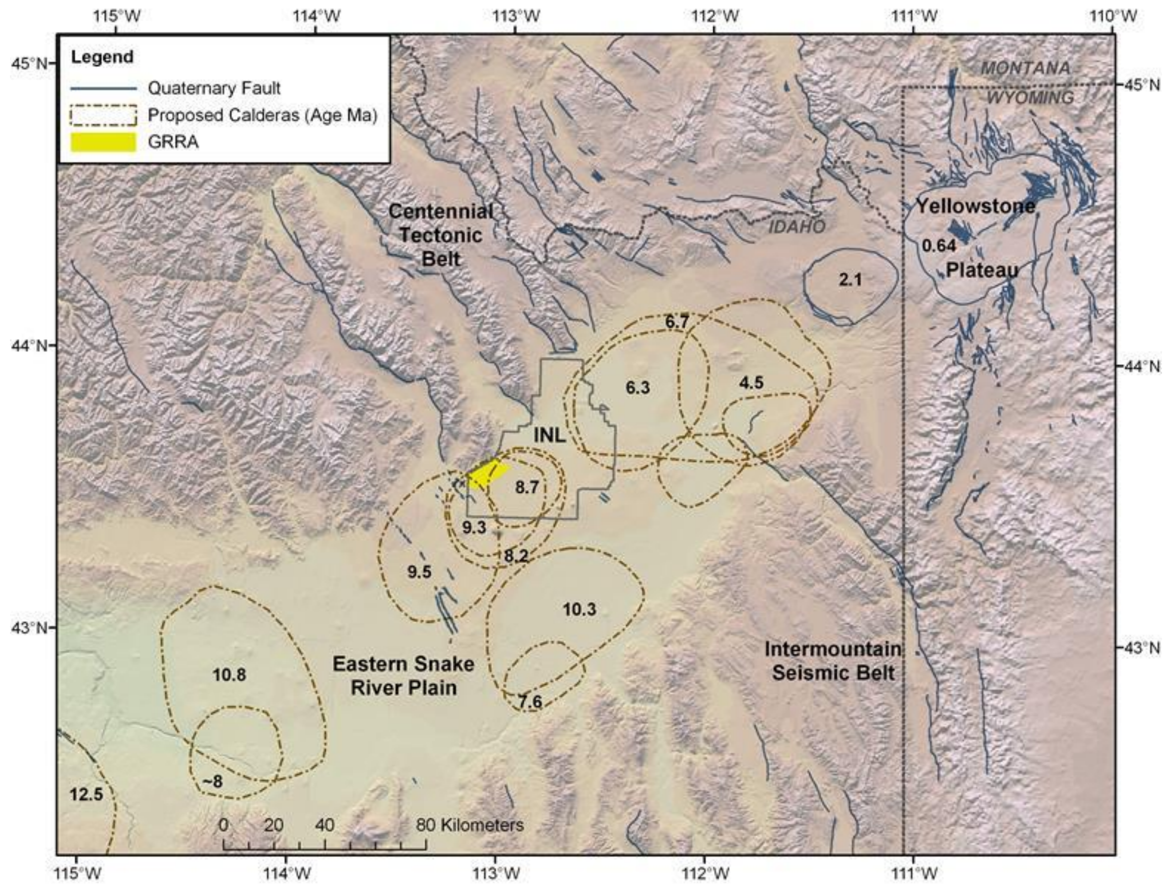


Figure 12. Map showing the northeast age migration of silicic volcanic centers associated with the Yellowstone hotspot. Proposed caldera boundaries and ages are adapted from Morgan and McIntosh (2005); Bonnichsen et al. (2008); Anders et al. (2009; 2014); McCurry et al. (2016).

Following hotspot volcanism, periodic basalt dike intrusions continued into the Pleistocene and Holocene in the ESRP. Basaltic vents are concentrated in northwest- and northeast-trending linear belts (Hackett et al., 2002) (Figure 13). The northwest-trending belts have associated ground deformation features produced from shallow dike intrusion and are referred to as volcanic rift zones (VRZs). Three of the four northwest-trending rift zones cross the INL Site along with the northeast-trending Axial Volcanic Zone (Hackett et al., 2002).

The VRZs are polygenetic features that formed through numerous cycles of volcanism. Investigators hypothesize that magma in the form of elongated sills and dikes having dimensions of tens of kilometers in length and <1 to 21 m (<3.2 to 69 ft) wide ascended from the upper mantle (~60-km [~35-mi] depth) (e.g., Leeman, 1982; Kuntz, 1992; Hughes et al., 1999; Holmes et al., 2008). As a dike ascends and dilates or laterally propagates in the shallow subsurface (at depths <4 km [<2.5 mi]), the dike forms features such as fissures, small normal faults, grabens, and monoclines above and ahead of it.

The northeastern corner of the GRRA overlaps with the northwestern end of the Howe-East Butte VRZ, and the southwestern end is within the Arco VRZ (Figure 13). The Howe-East Butte VRZ is poorly expressed surficially and is largely covered by basalt flows and fluvial and lacustrine sediments on the central INL Site (Kuntz et al., 1992). The VRZ is distinguished by five vents at its northwestern end, several isolated fissures (0.6- and 1.5-km [0.4- and 0.9-mi] lengths), and a positive northwest-trending aeromagnetic anomaly (Jackson, 1994; Hackett et al., 2002). The Arco VRZ contains volcanic fissures, monoclines, small normal faults, and vents dispersed across an ~18-km (~11-mi)-wide belt that formed by multiple cycles of volcanism during the period 600 ka to 10 ka (Kuntz et al., 1992; Kuntz et al., 1994; Kuntz et al., 2002). Lengths of the small normal faults, fissures, and monoclines within the Arco VRZ have lengths that range from 0.3 to 5 km (0.2 to 3 mi) (Jackson, 1994).

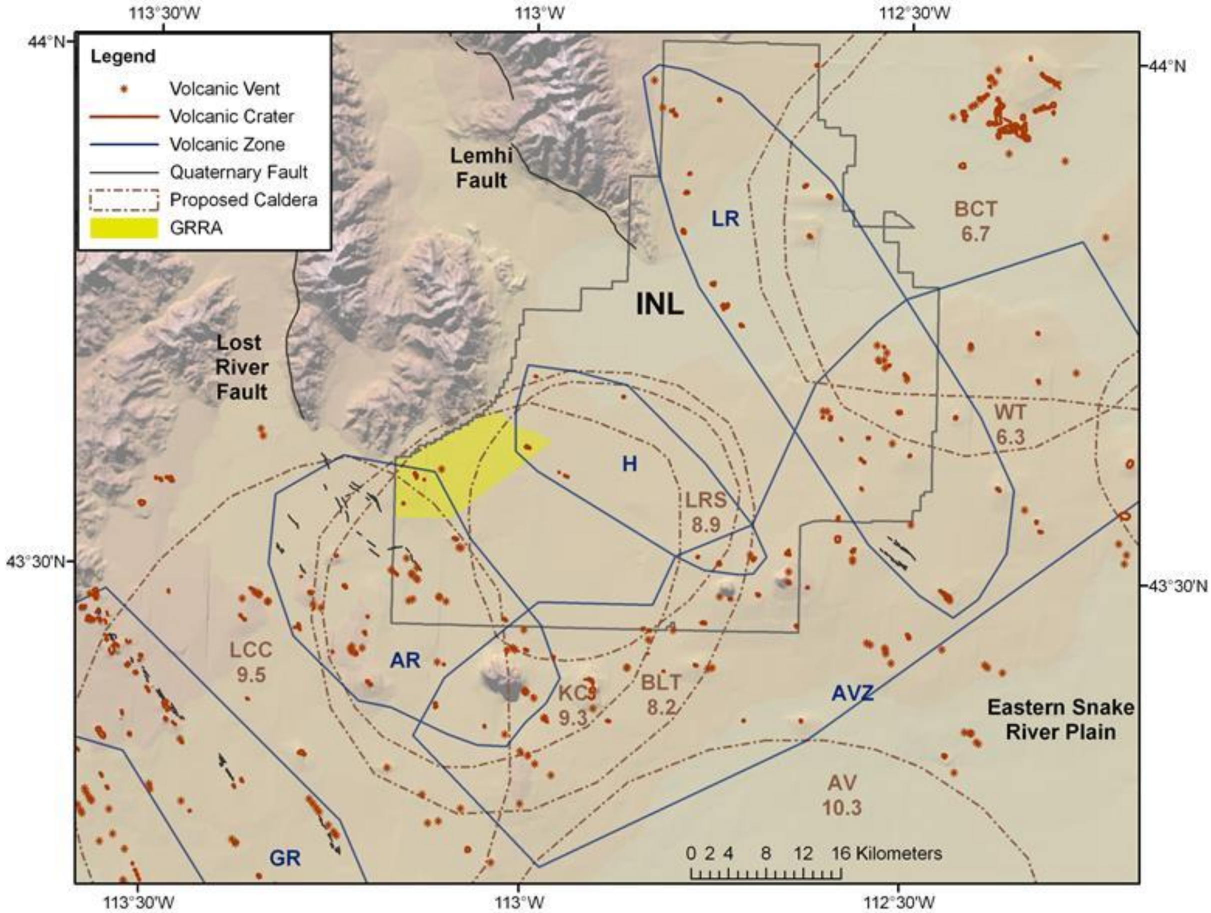


Figure 13. Locations of proposed caldera boundaries and VRZs at the INL Site and near the GRRA. Abbreviations: AR – Arco, H – Howe-East Butte, GR – Great Rift, LR – Lava Ridge-Hell's Half Acre Volcanic Rift Zones, and AVZ – Axial Volcanic Zone (blue); AV – Arbon Valley, BCT – Blacktail Creek, BLT – Big Lost Trough, KC – Kyle Canyon, LCC – Little Chokecherry, LRS – Lost River Sinks, WT - Walcott calderas with ages in Ma (brown).

The northwest-trending, southwest-dipping Lemhi and Lost River range-bounding normal faults are closest to the GRRA (Figure 13). Each fault has a southern end that may terminate at the end of its respective range or project beneath basalt flows into the ESRP (Bruhn et al., 1992; Wu and Bruhn, 1994; Rodgers et al., 2002). South of the GRRA, the Lost River fault may terminate in the northern end of the Arco VRZ. North of the GRRA, the Lemhi fault may terminate just south of the Lemhi Range based on seismic reflection profiles (Jackson et al., 2006). Paleoseismic data indicate that the most recent offsets along the southernmost segments of the Lost River and Lemhi faults occurred 15 to 25 ka (Hemphill-Haleyet al., 1992; Olig et al., 1995).

Prior to the northeast-southwest-oriented tectonic extension beginning at 16 m.y., two episodes of extension occurred in the Centennial Tectonic Belt with different orientations that were likely associated with changes in the Farallon and North American plate convergence rates in the Eocene (Wernicke et al., 1987; Janecke, 1992). Northwest-southeast-oriented extension first produced northeast-trending normal faults with a few kilometers of offset (48 to 49 Ma), and, when the direction of extension changed to west-southwest/east-northeast and southwest-northeast (48 to 46 Ma), north- to north-northwest-striking normal faults with >10-km (>6.2-mi) offsets formed (Janecke, 1992). The northeast-, north-, and north-northwest-trending normal faults are mapped within the footwalls of the Lost River, Lemhi, and Beaverhead faults. Near the GRRA, northeast-trending normal faults are mapped in the Arco Hills. These faults may have been reactivated during caldera formation (McCurry et al., 2016). A seismic refraction line that extends through the GRRA suggests the presence of a subsurface normal fault (Pankratz and Ackerman, 1982), which could have a northeast strike and southeast dip.

6.1.2 Seismicity

The regional earthquake catalog covers events occurring from 1850 to 2014 with magnitudes >2.0 (INL Seismic Monitoring, 2016). Locations for events prior to 1960 possess large errors, because they were based on few regional seismic stations or "felt" reports and not on local seismic networks. The distribution of seismicity in Figure 14 shows that epicenters form a distinct parabolic seismic zone around the ESRP. This zone also includes many Quaternary normal faults with Holocene offsets. This seismicity pattern encompasses the Centennial Tectonic Belt to the northwest of the ESRP and the Intermountain Seismic Belt to the southeast. At its northeastern apex in the Yellowstone Plateau, earthquakes are closest to the ESRP margins, and to the southwest, the distribution of seismicity flares outward away from the margins of the ESRP (Figure 14). Most notably, the ESRP has much less seismicity than the surrounding area.

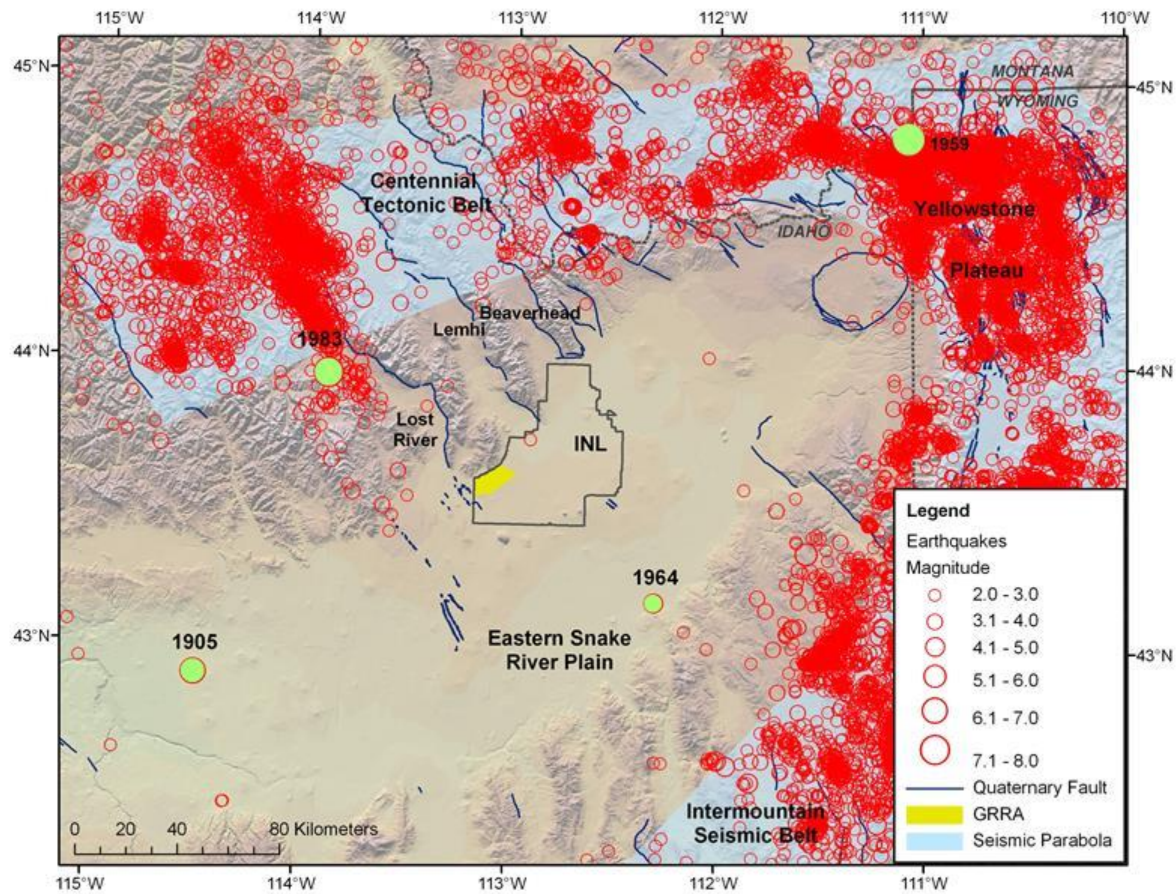


Figure 14. Map showing distribution of earthquake epicenters from 1850 to 2014 for magnitudes greater than 2.0. Green dots highlight locations of the following earthquakes: 1905 at Shoshone, Idaho; 1983 at Borah Peak, Idaho; 1959 at Hebgen Lake, Montana; and 1964 at ESRP.

A M_W 7.3 earthquake in 1959 at Hebgen Lake, Montana, and a M_W 6.9 earthquake in 1983 at Borah Peak, Idaho, are the largest normal faulting events in the region. They are well outside the SRP (Figure 14). The 1959 earthquake consisted of two subevents that ruptured the western-striking, southern-dipping (40 to 60 degrees) Hebgen and Red Canyon normal faults, producing maximum vertical displacements of 6.7 m (22 ft) over a surface scarp length of 23 km (14 mi) (Red Canyon) and 6.1 m (20 ft) over 14.5 km (9 mi) (Hebgen) (Myers and Hamilton, 1964; Doser, 1985). The 1983 Borah Peak, Idaho, earthquake ruptured two central segments of the northwest-striking, southwest-dipping (40 to 50 degrees) of the Lost River normal fault, producing a 36-km (22-mi)-long scarp with a maximum vertical displacement of 2.7 m (9 ft) (Richins et al., 1987; Crone et al., 1987). The 1959 and 1983 earthquakes nucleated at mid-crustal depths (~12 to 18 km [~7.5 to 11 mi) (Doser, 1985; Doser and Smith, 1989).

Historic pre-instrumental earthquakes have occurred near the ESRP, but large uncertainties in the location make it impossible to ascertain whether they truly lie within the SRP or are simply mislocated Basin and Range events. The 1905 Shoshone, Idaho, earthquake (Figure 14) is an example of this, but it occurred before there was instrumental monitoring in Idaho, and, because its epicenter was based on "felt" reports, it may have an error of 100 km (62 mi) or more. Oaks (1992) conducted a comprehensive investigation of historical records throughout an eight-state region to determine the magnitude and epicenter of the Shoshone earthquake. Using damage reports to assess Modified Mercalli Intensities, Oaks (1992) determined the 1905 earthquake to be a local magnitude (M_L) 5.5 ± 0.5 and its epicenter to be ~80 km (~50 mi) southeast of Shoshone outside the ESRP near the Idaho-Utah border. Another earthquake, an M 4.1 in 1964, was located along the eastern margin of the ESRP (Figure 14). With limited seismic station coverage at that time, the event likely has a large epicentral error and may or may not be located within the ESRP. Detailed investigations of this event have not been done.

Within the ESRP, only three fault plane solutions are available for microearthquakes of M_D<1.7, and all events are located within the INL Site boundaries (Figure 14). The composite fault plane solution for two events in 1989 (Jackson et al., 1993) and for two other microearthquakes, the 2006 M_D 1.7 and 2009 M_D 1.4, all show normal faulting with varying components of oblique slip and different nodal plane orientations (Figure 15).

No seismic events have been located in the GRRA, and only two microearthquakes with magnitudes of M_D 0.9 and 1.4 are located near the GRRA (Figure 15). The 1985 M_D 0.9 is located to north of the GRRA, and the 2001M_D 1.4 is located west of the GRRA (Figure 15). A 7-month microearthquake survey with 17 analog seismic stations spaced <2 km (<1.2 mi) apart was conducted in 1988 near the northern end of the GRRA (Jackson et al., 1989) (Figure 15). Two microearthquakes (M_D <0.5) were detected by the 1988 temporary array, but they were located outside of the array and outside the GRRA. There are no mapped faults at the surface within the GRRA (Kuntz et al., 1994). The GRRA is covered by basalt lava flows that are >519,000 years old (Kuntz et al., 1994). Geologic structures in addition to the two caldera boundaries may be present in the subsurface and may have formed in association with volcanic or tectonic extensional processes.

6.1.3 Probabilistic Seismic Hazard Analysis

The potential earthquake sources within the ESRP and surrounding Basin and Range regions that were identified prior to 1996 have been characterized as part of seismic source characterization models for probabilistic seismic hazard analyses (PSHAs) of INL nuclear facilities. The 2000 PSHA recomputed the hazard, which was first computed for the 1996 PSHA (Woodward-Clyde Federal Services et al., 1996). The INL PSHAs estimated ground-motion levels at each facility area and return periods of 2,500 and 10,000 years for earthquake sources and ground-motion models specific to the ESRP and the Basin and Range Province. The 2000 PSHA used the same seismic sources as in 1996 but updated the ground-motion models to those more applicable for normal faulting regimes (URS Greiner Woodward-Clyde

Federal Services, 1999; 2000). As an example, Figure 16 shows the mean and 5th to 95th percentile rock hazard curves for INTEC, which is located east of the GRRA in the central part of the INL Site (Figure 15).

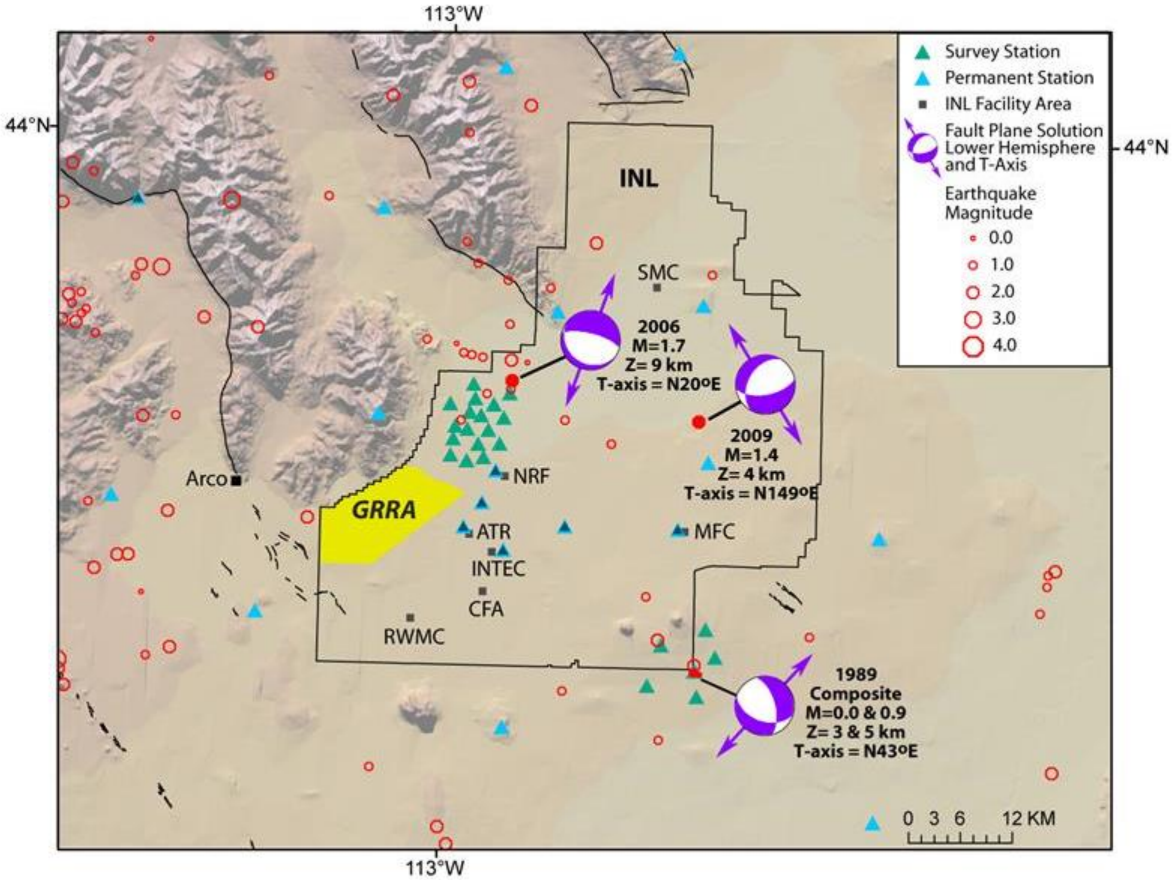


Figure 15. Lower hemisphere fault plane solutions (purple-and-white balls) and T-axis (purple arrows). The 1989 composite solution is from Jackson et al. (1993). Red dots show the locations of the earthquakes for the fault plane solutions. Text includes year, coda magnitude (M), depth, and T-axis orientation. Green triangles show the locations of the 1988 survey north of the GRRA and the 1989 survey at the southeastern corner of the INL Site.

The mean hazard curves of the 2000 PSHA form the basis for INL seismic design levels of existing facilities and provide baseline ground-motion estimates for comparisons with potential ground shaking levels of induced earthquakes. The example seismic hazard curves shown in Figure 16 can be used to assess the maximum magnitudes of induced earthquakes that will cause disruption to INL facility operations and the threshold magnitudes that FORGE stimulation activities will need to stay below.

For INL PSHAs, the seismic source characterization models included background seismicity zones within the Basin and Range Province and ESRP, VRZ earthquake sources, and fault-specific sources (Woodward-Clyde Federal Services et al., 1996). Each of the source models is characterized by the geographic locations, magnitude distributions, and recurrence models, and each source contributes to different levels of ground shaking to the seismic hazard.

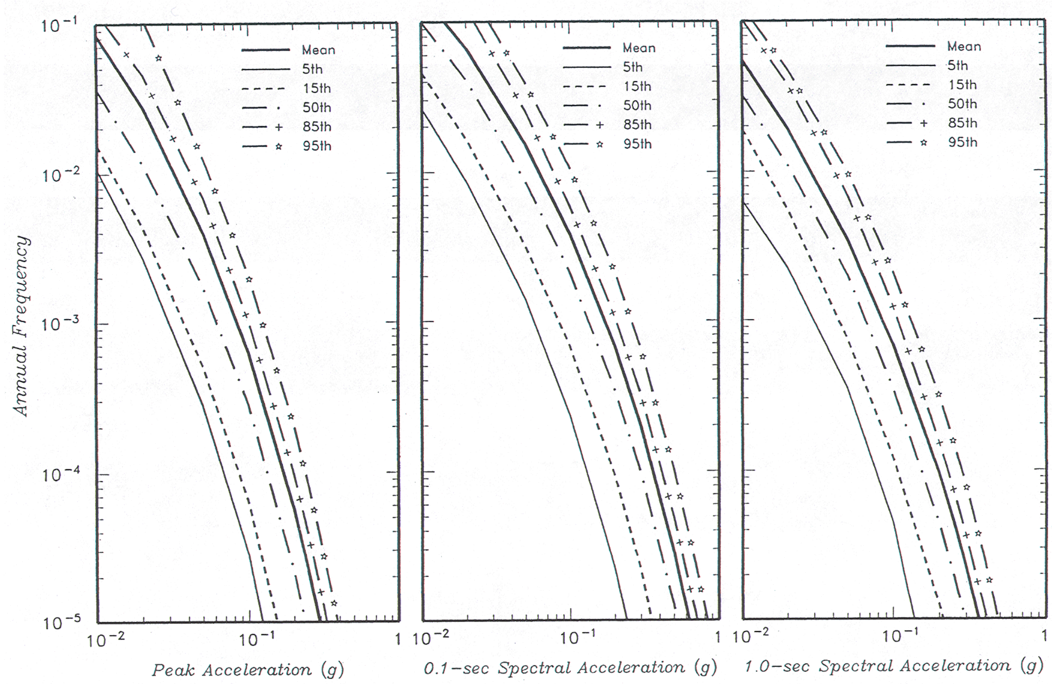


Figure 16. Mean and 5th to 95th percentile rock hazard curves for INTEC (URS Greiner Woodward-Clyde Federal Services, 1999).

For the ESRP source zone, the maximum magnitude was assigned to be Mw 5.5, and it was modeled to occur in the ESRP with a probability of 0.33. A maximum moment magnitude of 6.0 was assigned to the event with a probability of 0.67 when it did not occur within the ESRP. The approach for this characterization was based on the uncertainty of the 1905 Shoshone earthquake location and the lack of earthquakes to assess a recurrence rate in the ESRP.

VRZs in the ESRP were assigned a maximum moment magnitude earthquake of 5.0 ± 0.5 based on a compilation and evaluation of observed earthquake magnitudes associated with dike intrusion worldwide and estimates of moment magnitude using fault dimensions of small normal faults within ESRP VRZs and empirical magnitude-fault dimension relations. The recurrence rates for individual VRZs were based on the recurrence intervals of volcanism within their respective zones (16,000 to 100,000 years).

Due to their close proximity to the INL Site, three fault-specific sources for the Lost River, Lemhi, and Beaverhead faults where characterized with complex logic trees covering the magnitude distributions and recurrence. The moment magnitude distributions were assessed using empirical magnitude-fault dimension relations with segment lengths, seismogenic depth, and fault displacements based on available paleoseismic data. Earthquake recurrence for the fault sources were assessed using slip rates and, where available, recurrence intervals.

Results of the PSHA indicate that the hazard is driven by the fault-specific sources, which are capable of M_W 7+ events and background seismicity of the Basin and Range (M_W<6.5) source zones. Figure 17 shows that at PGA and spectral periods of 0.1 second (10 Hz) and 1 second (1 Hz), the faults contribute more to the levels of ground shaking at INTEC for return periods greater than 100 years (or annual frequencies of exceedance <10^{-2}) than the other sources. These hazard results also show that for return periods shorter than 10,000 years (or annual frequency of exceedance of 10^{-4}), volcanic earthquake source zones do not contribute significantly to hazard levels, because their recurrence estimates are much longer (>16,000 years) and their maximum magnitudes are lower (Figure 17). It is anticipated that small-magnitude earthquakes (<3) induced by FORGE activities will likely contribute less to ground shaking levels than those of the fault sources shown in Figure 17, but this will be assessed in a PSHA in Phase 2.

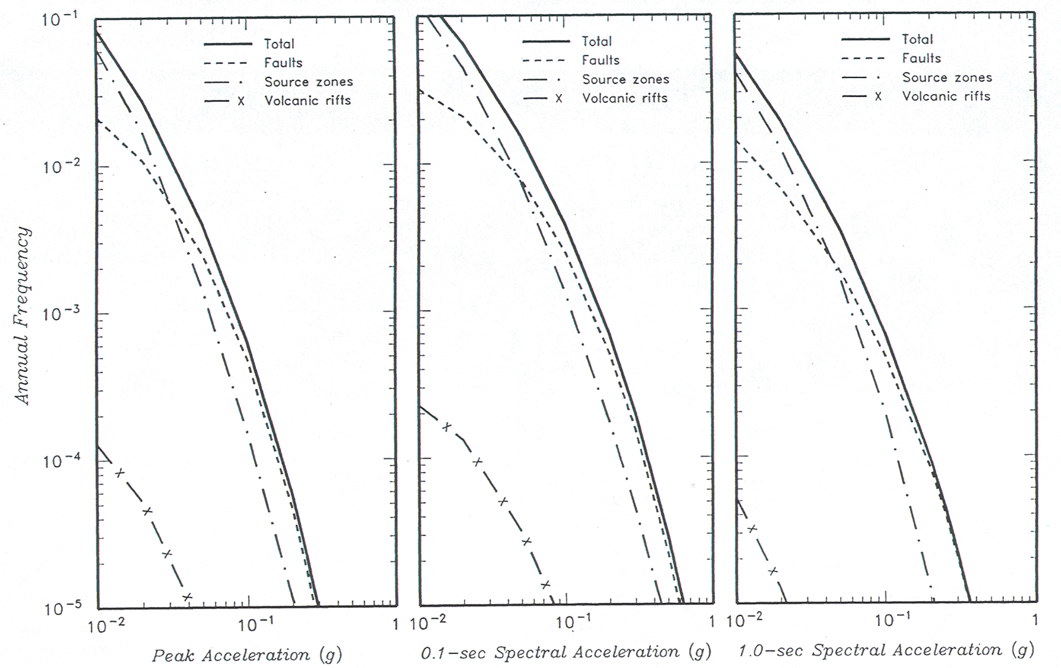


Figure 17. Contributions (or the levels of ground shaking) from fault sources, source zones, and VRZ sources to the rock mean hazard curve for INTEC (URS Greiner Woodward-Clyde Federal Services, 1999).

6.2 Hazard from Induced Seismicity

6.2.1 Nearby EGS Demonstrations

The nearby Raft River EGS demonstration, which has operated over the past several years, is located approximately 158 km (98 mi) from the FORGE site. The Raft River demonstration project has the objective to use thermal stimulation of a low-performing well within the existing Raft River geothermal system. To date, hundreds of millions of gallons of water have been injected into Well RRG-9 at the Raft River project site, with only one event over M 1.0 being recorded, i.e., a seismic event of M 1.01 recorded on October 1, 2011 (DOE, 2016). The Raft River and our proposed FORGE site share the same regional tectonic setting, further suggesting the low risk for induced seismic events.

6.2.2 EGS and Nuclear Operations

The extensive seismic hazard studies discussed in the previous section were required due to the nuclear facilities at the INL Site. We note that stimulation activities associated with oil and gas production are common near commercial nuclear plants (Figure 18), and we know of no adverse effects from these activities. Figure 18 shows that there are 108 and 1,659 wells located within the 8- and 16-km (5- and 10-mi), respectively, radius circles of nine commercial nuclear plants.

The largest natural earthquake near a nuclear power plant in the United States was the 2011 M 5.8 central Virginia earthquake, which occurred approximately 18 km (11 mi) west of the North Anna Power Station. No safety equipment was damaged during this event (NRC, 2012). An M 5.8 earthquake is far greater than the largest EGS or hydraulic stimulation event ever recorded.

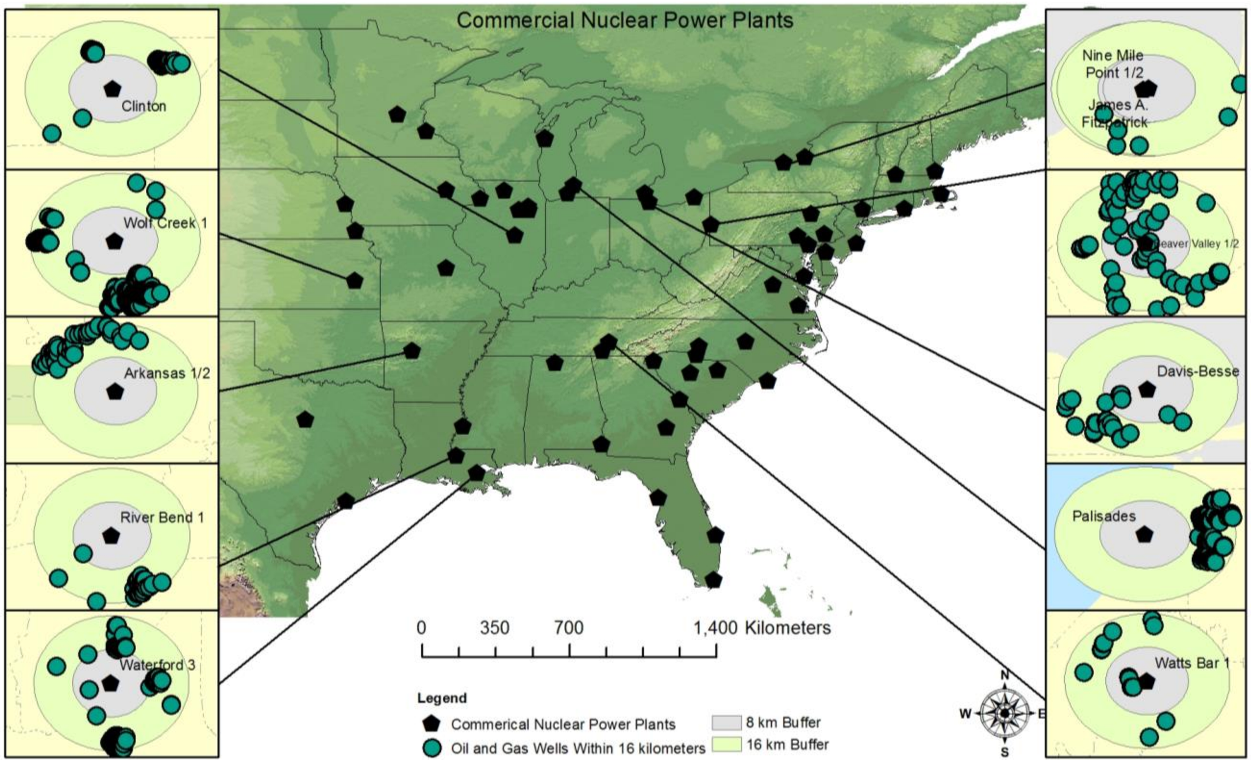


Figure 18. Maps showing the locations of commercial nuclear power plants and oil and gas wells within 8- and 16-km (5- and 10-mi) radius circles, which have induced seismicity due to stimulation activities.

7. SEISMIC RISK ANALYSIS

A full seismic risk analysis will be conducted for the region of interest during Phase 2 of the FORGE project. This will expand on the topics presented in the preliminary screening and provide much greater depth and detail. In particular, the full seismic risk analysis will build on the considerable work conducted as part of the existing PSHA studies for INL facilities, as well as the potential impact on the towns within the expected radius of influence. The analysis will include seismic impacts, as well as ground noise and vibration.

In general terms, a seismic risk analysis occurs after assessing the additional hazard from induced seismicity with respect to the baseline natural seismicity. The calculation of the risk associated with the creation and operation of FORGE can be compared to the prior baseline risk. For INL, the advantage is that substantial work in estimating seismic hazard and risk has already been done. Existing risk analysis software, such as HAZUS (2010) or SELENA (2010), will be employed to compute the risk of physical damages in monetary terms. Results of the risk analysis will be presented as maps of physical damage, nuisance, and economic loss risk.

The first step in characterizing ground motion is the development of PSHAs to estimate PGA. Because PSHAs of natural seismicity have already been developed for this site, accommodating the slight extra risk for the EGS seismicity will be straightforward. The major difference will be the much smaller expected magnitude of the EGS seismicity.

The next step is to define the potential impacts and assets that could be affected. For the INL Site, the impacts fall into two broad classes: INL Site facilities and nearby small towns. We use previous studies as a guide and appropriate available software (e.g., HAZUS, SELENA, RiskScape, Crisis, OpenRisk) to evaluate the potential vulnerability. We expect the available software to be most useful for the non-INL residents and structures and will base the potential INL impacts on previous seismic hazard studies. Overall, the damage potential is likely to be small, with the highest impact at the nuisance level. The presentation of the results is possibly the most important step and will be done in coordination with outreach efforts.

8. RISK-BASED MITIGATION PLAN

To mitigate the risks associated with induced seismicity, a systematic and structured risk-based mitigation plan must focus on all sources of risk, including technical and nontechnical risks. We have identified five sources of risk and created individual mitigation measures for each in the subsections below. The five sources of risk are:

1. Lack of stakeholder and public acceptance
2. Unexpected magnitude of induced seismic event
3. Unexpected location of induced seismic event
4. Nuisance
5. Damage to structures.

Figure 19 illustrates operation during normal, elevated, and crisis conditions. The stages are denoted by green, yellow, and red—analogous to a traffic light. The stages correspond to either unexpected ground motion (peak ground velocity [PGV]) or an event in an unexpected location. For example, during normal operation, PGV due to seismic events is no greater than 0.5 cm per second (0.2 in. per second). The correspondence between stage and ground motion is explained in Section 8.2.

8.1 Lack of Stakeholder and Public Acceptance

Mitigation Measure: Create and continually adapt a communications and outreach program aimed at increasing public knowledge of the expected behavior of induced seismicity at the FORGE site.

The first risk of any EGS project is a lack of stakeholder and public acceptance of the project. An EGS resource that is engineered to yield an acceptably low probability of seismic events must still get support from local communities, special interest groups, regulators, non-governmental organizations, and government officials. The communications and outreach program described in Section 3 of this plan and in the FORGE *Communications and Outreach Plan* (Ulrich and Podgorney, 2016) is a fluid program aimed at determining the current level of public knowledge of induced seismicity, communicating the benefits and risks associated with induced seismicity and the FORGE project as a whole, and incorporating stakeholder feedback into the program to facilitate public acceptance. The program should be in place and active during all phases of the project.

The project has broad stakeholder and public support, as evidenced by the letters of support listed in Appendix A, Table A-2. To date, no individual or group has opposed establishing FORGE on the INL Site. The communications and outreach program will continue to engage with stakeholders and the public using tactics laid out in Section 3 of this plan and in the FORGE *Communications and Outreach Plan* (Ulrich and Podgorney, 2016).

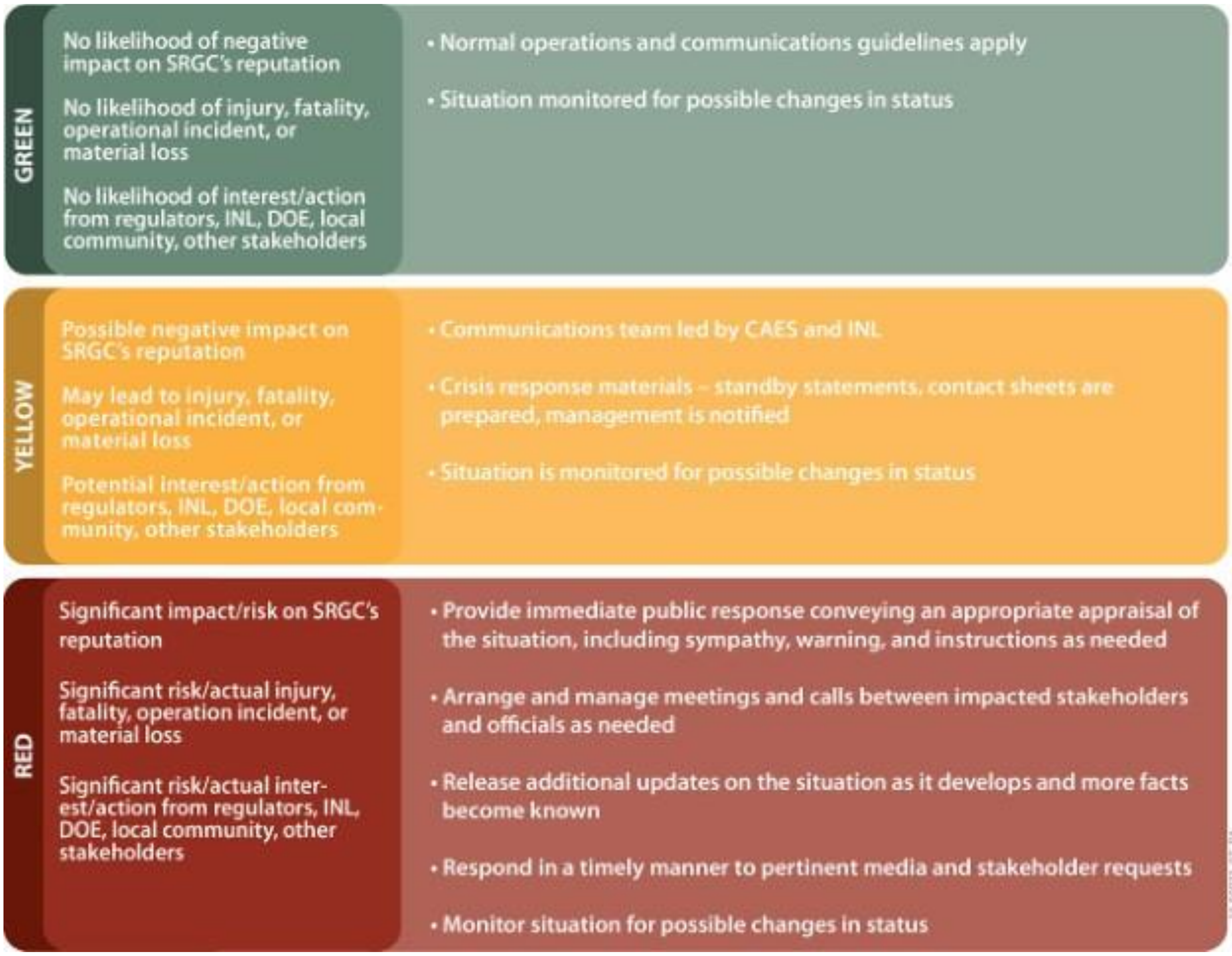


Figure 19. General guidance regarding appropriate responses during normal operations and in the event of a crisis.

8.2 Unexpected Magnitude of Induced Seismic Event

Mitigation Measure: Initiate operational controls based on the size of the event as determined by either magnitude or ground motion (PGV). Create an exception report, and begin near real-time communications, as outlined in the *Communications and Outreach Plan* (Ulrich and Podgorney, 2016), for transparent reporting of situational assessment and current mitigation measures.

Ground-motion-modeling maps that we create during Phase 2A of the project will estimate associated PGA or PGV for a specific-magnitude event within the reservoir. Based on these estimates, and incorporating the Phase 2 PSHA results for induced seismic events, the specific ground-motion ranges for initiation of operational controls can be determined. A description of the expected exception reports and other communication action plans (as described in Sections 3 and 5) can be added at the appropriate levels.

In the following text, we describe scenario events along with very approximate PGV levels (adapted from Wald et al., 1999). The associated traffic light control system marker is listed (green, yellow, or red) (Majer et al., 2014). These estimates will be revised in Phase 2, along with expected injection mitigation, based on models and community response.

It may also be necessary to adjust injection response, because experience has shown that significant seismicity can occur after injection ceases.

Green traffic light – PGV less than 0.5 cm per second (0.2 in. per second). Not felt except in exceptional circumstances. Operations continue. If a small seismic event were to occur, normal operations would continue. Most of the seismic events expected to be induced by normal reservoir activities are projected to be less than M 2.0. For comparison, the largest magnitude event within the ESRP during the time period for which seismic records have been available (currently 34 years) has been an M 2.2 event. Events less than M 2.0 are not a cause of concern.

Yellow traffic light – PGV between 0.5 and 3.9 cm per second (0.2 and 1.5 in. per second). Felt weakly to lightly by residents in the area; no possibility of damage. Pumping proceeds with caution, and observations are intensified. For ground motion in this range, fluid injection is modified to preserve both the current flow rate and wellhead pressure for an observation period at of least a 24 hours. However, to keep the wellhead pressure from increasing, it may be necessary to decrease the flow rate. Additionally, if another event within this magnitude range were to occur within the observation period, field operations would be further modified to decrease the wellhead pressure by at least a predetermined value from the current level, and the observation period would be extended for an additional 24 hours. If ground motion is maintained at or below the threshold for at least 24 hours, at the conclusion of the observation period, the flow rate and wellhead pressure may be gradually increased over 24 hours to the pre-event level.

Red traffic light – PGV between 3.9 and 9.2 cm per second (1.5 and 3.6 in. per second). Moderate shaking to residents in the area. Minor damage is possible for susceptible structures. For ground motions of 3.9 cm per second (1.5 in. per second) or greater, fluid injection operations would be modified to stop injection and flow the well. In this scenario, the well would be flowed to relieve pressure within the reservoir. Resumption of injection would take place after coordination and discussion by SRGC and DOE.

8.3 Unexpected Location of Induced Seismic Event

Mitigation Measure: Initiate operational controls based on the size of the event and begin communications, as outlined in the FORGE *Communications and Outreach Plan* (Ulrich and Podgorney, 2016), for transparent reporting of situational assessment and current mitigation measures. If a well-located induced seismic event were to occur outside the horizontal and vertical region of the expected reservoir seismic activity zone, the event would be deemed an outlier. Events would be considered outliers if they occur significantly away from the region of the well in which injection is, or was recently, taking place. The threshold will be based on location accuracy and operational experience. Additional operational measures would be initiated based on the size and number of additional events (if any) in the outlier group. If two or more outlier seismic events were to occur, the fluid stimulation zone within the well would be modified.

8.4 Nuisance

Mitigation Measure: Adhere to safeguards and operational procedure modifications for excessive magnitude seismicity and outlier seismicity, as described above, to minimize the likelihood of felt events. Continue communications and outreach program protocols for clear two-way communication between the project and local communities. If small-magnitude earthquakes that could potentially disrupt human activities (such as sleeping) occur but do not cause damage to surface structures, a clear communication pathway is necessary between the project proponents, local communities, and INL facility operators to mitigate the effect of the nuisance events. The *Communications and Outreach Plan* (Ulrich and Podgorney, 2016) has in place easy-to-understand protocols that will allow the project proponents to determine the level of concern and allow concerns from the local communities and INL facility operators to be heard. Any resulting changes in operational procedure will be communicated to local communities and INL facility operators, including those at ATR. Regularly scheduled briefings will be held with INL facility points of contact.

8.5 Damage to Structures

Mitigation Measure: Adhere to safeguards and operational procedure modifications for excessive-magnitude seismicity and outlier seismicity, as described above, to minimize the likelihood of felt events. Continue communications and outreach program protocols for transparent reporting of situational assessment and current mitigation measures.

Due to the remoteness of the FORGE site and small size of past events, physical damage is highly unlikely. Nevertheless, a protocol will be developed to address any damage claims. For example, if shaking is greater than PGA 0.05 g is recorded on strong-motion seismometers, surface structures near the injection site could sustain minor cosmetic damage. If this is the case, we would accept damage reports from the affected areas for 3 months after the event. Damage reports would be available online on the SRGC website and would also be available via phone and mail. Notices of the availability of the damage claim procedure would be sent out via email, provided online, and placed in local newspapers. A licensed, independent civil engineer would evaluate all claims. We are investigating the possibility of payment using a third-party liability insurance policy.

9. CONCLUSION

To date, the response of the local communities, regulators, and public officials to the FORGE project has been positive. Our communications and outreach program has been in place for several years, and we will maintain and expand the current level of support among our stakeholders and the general public with regard to the FORGE project. Technical analyses have been conducted and are planned for Phase 2 of the project to quantify the hazard and risk of induced seismicity. Five risks have been identified, and programs have been put in place to mitigate those risks.

Based on these analyses, and taking into consideration the interactions with local communities, we gauge the overall risk level to be low. We believe that we can proceed with the planning, but, as indicated above, we have identified specific additional analyses for Phase 2 that are necessary to verify the above results are robust.

10. PHASE 2 PLAN

At the conclusion of FORGE Phase 2, this plan will be finalized and will include all of the data collected and results of analyses performed for Phase 1, as well as all of the proposed analyses called for in Phases 2A and 2B. These analyses will include:

1. Phase 2A – Deployment of additional seismic stations around the FORGE site and data analysis.
2. Phase 2B – Finalization of the mitigation plan. This will include:
    - (a) Rigorous determination of the region of influence from ground-motion modeling analysis and estimation of typical seismic event sizes from a site-specific, probabilistic, seismic hazard analysis of induced events
    - (b) Rigorous determination of lower and upper bounds of potential damage within the radius of influence
    - (c) Complete review of state and local regulations and ordinances related to noise and vibration disturbances
    - (d) Comparison of baseline ground vibrations with ground vibrations from anticipated EGS seismic events
    - (e) Completion of a baseline analysis of aboveground noise

(f) Finalization of radius-of-interest and trigger values for seismicity reports based on modeling study results

(g) Evaluation of site-specific induced seismicity hazards

(h) Full analysis of the region-of-interest seismic risk

(i) Finalization of the mitigation plan's potential operational procedure modifications, nuisance plan, and structural damage criteria estimates

(j) Exploration of other mitigation measures, such as liability insurance.

Additionally, during Phase 2C, a permanent, continuous, high-resolution surface and borehole seismic network will be installed that complies with the recommendations produced in the finalized version of this plan. This monitoring will be continued into Phase 3, and seismic monitoring data will be made available to the community through the project website in real time or as near real time as is technically possible.

REFERENCES

42 U.S.C. §§4321-4370h, 1970, National Environmental Policy Act.

ANSI S2.71-1983 (R2006) (formerly ANSI S3.29-1983), Guide to the Evaluation of Human Exposure to Vibration in Buildings, American Standards Institute.

Anders, M.H., Rodgers, D.W., Hemming, S.R., Saltzman, J., DiVenere, V.J., Hagstrum, J.T., Embree, G.F., and Walter, R.C., 2014, A fixed sublithospheric source for the late Neogene track of the Yellowstone hotspot: Implications of the Heise and Picabo volcanic fields: Journal of Geophysical Research, v. 119, p. 2871–2906, doi:10.1002/2013JB010483.

Anders, M.H., Saltzman, J., and Hemming, S.R., 2009, Neogene tephra correlations in eastern Idaho and Wyoming: Implications for Yellowstone hotspot-related volcanism and tectonic activity: Geological Society of America Bulletin, v. 121, p. 837–856.

Bonnichsen, B., Leeman, W.P., Honjo, N., McIntosh, W.C., and Godchaux, M.M., 2008, Miocene silicic volcanism in southwestern Idaho: Geochronology, geochemistry, and evolution of the central Snake River Plain: Bulletin of Volcanology, v. 70, p. 315–342.

Braile, L.W., Smith, R.B., Ansorge, J., Baker, M.R., Sparlin, M.A., Prodehl, C., Schilly, M.M., Healy, J.H., Mueller, S.T., and Olsen, K.H., 1982, The Yellowstone-Snake River Plain Seismic Profiling Experiment: Crustal Structure of the Eastern Snake River Plain: Journal of Geophysical Research, v. 87, p. 2597–2609.

Branney, M.J., 1995, Downsag and extension at calderas: new perspectives on collapse geometries from ice-melt, mining, and volcanic subsidence: Bulletin of Volcanology, v. 57, p. 303–318.

Bruhn, R.L., Wu, D., and Lee, J-J, 1992, Final Report on the structure of the southern Lemhi and Arco fault zone, Idaho: EG&G Informal Report EGG-NPR-10680, p. 26.

Crone, A.J., Machette, M.N., Bonilla, M.G., Lienkaemper, J.J., Pierce, K.L., Scott, W.E., and Bucknam, R.C., 1987, Surface faulting accompanying the Borah Peak earthquake and segmentation of the Lost River fault, central Idaho: Bulletin of the Seismological Society of America, v. 77, p. 739–770.

CTD, 2013, Transportation and Construction Vibration Guidance Manual: California Department of Transportation, CT-HWANP-RT-13-069.25.3, 190 p.

DOE, 2016, EGS: Interactive, Map of Earthquakes at Raft River: http://esd1.lbl.gov/research/projects/induced_seismicity/egs/raft_river.html (accessed March 2016).

DOE-ID, 2004, Idaho National Engineering Laboratory Groundwater Protection Management Plan: DOE/ID-11176, U.S. Department of Energy Idaho Operations Office.

Doser, D.I., 1985, Source parameters and faulting processes of the 1959 Hebgen Lake, Montana, earthquake sequence: Journal of Geophysical Research, v. 90, p. 4537–4555.

Doser, D.I., and Smith, R.B., 1989, An assessment of source parameters of earthquakes in the Cordillera of the western United States: Bulletin Seismological Society of America, v. 79, p. 1383–1409.

Dowding, C.H., 1996, Construction Vibrations: Prentice Hall.

Foulger, G.R., and Julian, B.R., 2013, Report to AltaRock Energy Inc.: Earthquake Seismicity Associated with the Newberry EGS Demonstration.

FTA, 2006, Transit Noise and Vibration Impact Assessment: Federal Transit Administration, FTA-VA-90-1003-06, 19 p.

HAZUS, 2010, Hazus: http://www.fema.gov/hazus.

Hackett, W.R., Smith, R.P., and Khericha, S., 2002, Volcanic hazards of the Idaho National Engineering and Environmental Laboratory, southeast Idaho, *in* Bonnichsen, B., White, C.M., and McCurry, M., eds., Tectonic and Magmatic Evolution of the Snake River Plain Volcanic Province, Idaho: Idaho Geological Survey Bulletin 30, p. 461–482.

Hemphill-Haley, M.A., Knuepher, P.L., Forman, S.L., and Smith, R.P., 1992, Paleoseismic investigations of the southern Lemhi Fault, Idaho: EG&G Informal Report EGG-GEO-10178, p. 1–32.

Holmes, A.A.J., Rodgers, D.W., and Hughes, S.S., 2008, Kinematic analysis of fractures in the Great Rift, Idaho: Implications for subsurface dike geometry, crustal extension, and magma dynamics: Journal of Geophysical Research, v. 113, B04202, doi:10/1029/2006JB004782.

Hughes, S.S., Smith, R.P., Hackett, W.R., and Anderson, S.A., 1999, Mafic volcanism and environmental geology of the Eastern Snake River Plain, Idaho, *in* eds., Hughes, S.S., and Thackray, G.D., Guidebook to the Geology of Eastern Idaho: Idaho Museum of Natural History, p. 143–168.

Idaho Department of Environmental Quality, 2007, Guidance for Reclamation and Reuse of Municipal and Industrial Wastewater, 563 p.

INL Seismic Monitoring, 2016, Unpublished earthquake data compiled by the INL Seismic Monitoring program and provided to the Snake River Geothermal Consortium, Idaho National Laboratory, Idaho Falls, Idaho.

Irving, J., and Podgorney, R.K., 2016, Environmental Information Synopsis: Snake River Geothermal Consortium, INL/LTD-16-38126.

ISO 2631-2, 2003, Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 2: Vibration in buildings (1 Hz to 80 Hz), International Organization of Standardization.

Gorman, V.W., and Guenzler, R.C., 1983, The 1983 Borah Peak earthquake and INEL structural performance: EG&G Informal Report EGG-EA-6501, p. 76.

Jackson, S.M., 1994, Magnitudes of earthquakes associated with basalt dike intrusion for use in INEL seismic hazards evaluations: Lockheed Idaho Technologies Company, INEL-94/0132, p. 44.

Jackson, S. M., Anderson, D.M., Carpenter, G.S., Gilbert, H.K., Martin, S.M., and Permann, P.J., 1989, The 1988 INEL Microearthquake Survey near the Western Edge of the eastern Snake River Plain: EG&G Internal Technical Report EGG-BEG-8665, August, p. 48.

Jackson, S.M., Carpenter, G.S., Smith, R.P., and Casper, J.L., 2006, Seismic reflection project near the southern terminations of the Lost River and Lemhi faults, eastern Snake River Plain, Idaho: Battelle Energy Alliance, INL/EXT-06-11851, p. 16.

Jackson, S. M., Wong, I.G., Carpenter, G.S., Anderson, D.M., and Martin, S.M., 1993, Contemporary Seismicity in the eastern Snake River Plain, Idaho based on Microearthquake Monitoring: Bulletin of the Seismological Society of America, v. 83, p. 680–695.

Janecke, S.U., 1992, Kinematics and timing of three superimposed extensional systems, east central Idaho: Evidence for an Eocene tectonic transition: Tectonics, v. 11, p. 1121–1138.

Kuntz, M.A., 1992, A model-based perspective of basaltic volcanism, eastern Snake River Plain, Idaho, *in* eds., Link, P. K., Kuntz, M. A., and Platt, L. B., Regional Geology of Eastern Idaho and Western Wyoming: Geological Society of America Memoir 179, p. 289–304.

Kuntz, M.A., Anderson, S.R., Champion, D.E., Lanphere, M.A., and Grunwald, D.J., 2002, Tension cracks, eruptive fissures, dike, and faults related to late Pleistocene – Holocene basaltic volcanism and implications for the distribution of hydraulic conductivity in the eastern Snake River Plain, Idaho, *in* Link, P.K., and Mink, L.L., eds., Geology, Hydrogeology, and Environmental Remediation: Idaho National Engineering and Environmental Laboratory, Eastern Snake River Plain, Idaho, Boulder, Colorado: Geological Society of America Special Paper 353, p. 111–133.

Kuntz, M.A., Covington, H.R., and Schorr, L.J., 1992, An overview of basaltic volcanism of the eastern Snake River Plain, Idaho, *in* Link, P. K., Kuntz, M. A., and Platt, L.B., eds., Regional Geology of Eastern Idaho and Western Wyoming: Geological Society of America Memoir, v. 179, p. 227-267.

Kuntz, M.A., Skipp, B., Lanphere, M.A., Scott, W.E., Pierce, K.L., Dalrymple, G.B., Champion, D.E., Embree, G.F., Page, W.R., Morgan, L.A., Smith, R.P., Hackett, W.R., and Rodgers, D.W., 1994, Geologic map of the Idaho National Engineering Laboratory and adjoining areas, eastern Idaho, U.S. Geological Survey Miscellaneous Investigation Map, I-2330, 1:100,000 scale.

Leeman, W.P., 1982, Development of the Snake River Plain-Yellowstone Plateau Province, Idaho and Wyoming: An overview and petrologic model, *in* Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic Geology of Idaho: Idaho Geological Survey Bulletin 26, p. 155-178.

Majer, E., Nelson, J., Robertson-Tait, A., Savy, J., and Wong, I., 2012, Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems, DOE/EE-0662, U.S. Department of Energy: https://www1.eere.energy.gov/geothermal/pdfs/geothermal_seismicity_protocol_012012.pdf (accessed March 2016).

Majer E., Nelson, J., Robertson-Tait, A., Savy, J., and Wong, I., 2014, Best Practices for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems (EGS), LBNL Paper LBNL-6532E: http://escholarship.org/uc/item/3446g9cf (accessed March 2016).

McCurry, M., McLing, T., Smith, R., Hackett, W., Goldsby, R., Lochridge, W., Podgorney, R.K., Wood, T., Pearson, D., Welhan, J., and Plummer, M., 2016, Geologic Setting of the Idaho National Laboratory Geothermal Resource Research Area, *in prep*.

McGarr, A., Bekins, B., Burkardt, N., Dewey, J., Earle, P., Ellsworth, W., Ge, S., Hickman, S., Holland, A., Majer, E., Rubinstein, J., and Sheehan, A., 2015, Coping with earthquakes induced by fluid injection: Science, v. 347, no. 6224, p. 830–831, doi:10.1126/science.aaa0494.

McNamara, D.E., and Buland, R.P., 2004, Ambient noise levels in the Continental United States: Bulletin of the Seismological Society of America, v. 94, p. 1517–1527.

Metcalfe, E., 2015, Road Tripping through the Geothermal Frontier: http://energy.gov/eere/articles/road-tripping-through-geothermal-frontier (accessed March 2016).

Morgan, L.A., and McIntosh, W.C., 2005, Timing and development of the Heise volcanic field, Snake River Plain, Idaho, western USA: Bulletin of the Seismological Society of America, v. 117, p. 288–306.

Myers, W.B., and Hamilton, W., 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959: U. S. Geological Survey Bulletin 435-I, p. 55–98.

NRC, 2012, The North Anna Earthquake – One Year Later: http://public-blog.nrc-gateway.gov/2012/08/23/the-north-anna-earthquake-one-year-later/ (website visited March 2016).

Oaks, S.D., 1992, Historical seismicity investigation for the November 11, 1905 earthquake: EG&G Informal Report EGG GEO 10203, p. 106.

Olig, S.S., Gorton, A.E., Bott, J.D., Wong, I.G., Knuepher, P.L.K., Forman, S.L., Smith, R.P., and Simpson, D., 1995, Paleoseismic investigation of the southern Lost River fault zone: Idaho, Lockheed Idaho Technologies Company, INEL-95/0508, p. 82.

Pankratz, L.W., and Ackerman, H.D., 1982, Structure along the northwest edge of the Snake River Plain interpreted from seismic refraction: Journal of Geophysical Research, v. 87, p. 2676–2682.

Payne, S.J., Bruhn, D.F., Hodges, J.M., and Berg, R.G., 2014, INL Seismic Monitoring Annual Report: January 1, 2012 – December 31, 2012: INL/EXT-14-33937.

Richins, W.D., Pechmann, J.C., Smith, R.B., Langer, C.J., Goter, S.K., Zollweg, J.E., and King, J.J., 1987, The 1983 Borah Peak, Idaho earthquake and its aftershocks: Bulletin of the Seismological Society of America, v. 77, p. 694–723.

Rodgers, D.W., Ore, H.T., Bobo, R.T., McQuarrie, N., and Zentner, N., 2002, Extension and subsidence of the eastern Snake River Plain, Idaho, *in* Bonnichsen, B., White, C.M., and McCurry, M., eds., Tectonic and Magmatic Evolution of the Snake River Plain Volcanic Province, Idaho: Idaho Geological Survey Bulletin 30, p. 121–155.

Rubenstein, J.L., and Mahani, A.B., 2015, Myths and Facts on Wastewater Injection, Hydraulic Fracturing, Enhanced Oil Recovery, and Induced Seismicity: Seismological Research Letters, v. 86, no. 4, 8 p.

SELENA, 2010, The SELENA-RISE Open Risk Package: http://sourceforge.net/projects/selena.

Shapiro, S.A., Dinske, C., Langebruch, C., and Wenzel, F., 2010, Seismogenic index and magnitude probability of earthquakes induced during reservoir fluid stimulations: The Leading Edge, Special Section: Microseismic, p. 304–309.

Siskind, D.E., 2000, Vibrations from Blasting: Cleveland, Ohio, International Society of Explosives Engineers, 120 p.

Siskind, D.E., Stagg, M.S., Kopp, J.W., and Dowding, C.H., 1980, Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting: U.S. Bureau of Mines Report RI 8507.

Smith, P., Visser, C., and Richard, W., 2016, Environmental, Safety, and Health Plan: Snake River Geothermal Consortium, INL/LTD-16-38125.

Sparlin, M., Braile, L.W., and Smith, R.B., 1982, Interpretation of Seismic Profiles across the Eastern Snake River Plain (abstract): EOS Transactions American Geophysical Union, v. 60, no. 46, p. 941.

St. Clair, J., et al., 2016, Geologic Conceptual Model: Snake River Geothermal Consortium, INL/LTD-16-38121.

Street, L.V., Idaho National Engineering and Environmental Laboratory, to D. Dunn, Idaho Department of Water Resources, September 4, 2001, INEEL Comprehensive Well Surveys and Annual Water Use Reports: CCN 25370.

Ulrich, J., and Podgorney, R.K., 2016, Communications and Outreach Plan: Snake River Geothermal Consortium, INL/LTD-16-38119.

URS Greiner Woodward-Clyde Federal Services, Geomatrix Consultants, and Pacific Engineering and Analysis, 1999, Final Report: Development of Design Basis Earthquake Parameters for TMI-2 Independent Spent Fuel Storage Installation at the INEEL, Bechtel BWXT Idaho, LLC, INEEL/EXT-99-00619.

URS Greiner Woodward-Clyde Federal Services, Geomatrix Consultants, and Pacific Engineering and Analysis, 2000, Recomputation of the Seismic Hazard at the Idaho National Engineering and Environmental Laboratory, Bechtel BWXT Idaho, LLC, INEEL/EXT-99-00786.

Wald, D.J., Quitoriano, V., Heaton, T.H., and Kanamori, H., 1999, Relationships between peak ground acceleration, peak ground velocity, and modified Mercalli intensity in California: Earthquake Spectra, v. 15, no. 3, 557–564

Weers, J., and Podgorney, R.K., 2016, Data Dissemination and Intellectual Property Plan: Snake River Geothermal Consortium, INL/LTD-16-38120.

Weingarten, M., Ge, S., Godt, J.W., Bekins, B.A., and Rubenstein, J.L., 2015, High-rate injection is associated with the increase in U.S. mid-continent seismicity: Science, v. 348, p. 6241.

Wernicke, B.P., Christiansen, R.L., England, P.C., and Sonder, L.J., 1987, Tectonomagmatic evolution of Cenozoic extension in the North American Cordillera, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L., eds., Continental Extensional Tectonics: Geological Society of America Special Publication, v. 28, p. 203–221.

Woodward-Clyde Federal Services, Geomatrix Consultants, and Pacific Engineering and Analysis, 1996, Site-specific Seismic Hazard Analyses for the Idaho National Engineering Laboratory, Volume I Final Report and Volume 2 Appendix, Lockheed Idaho Technologies Company, INEL-95/0536.

Wu, D., and Bruhn, R.L., 1994, Structural and rupture characteristics of the southern Lost River fault zone, Idaho, University of Utah, Report to Woodward-Clyde Federal Services, p. 33.

Appendix A

Communications and Outreach: Meetings, Presentations, and Letters of Support

Appendix A
Outreach and Communication: Meetings, Presentations, and Letters of Support

Table A-1. List of meetings and discussions with community leaders, INL management, regulators, and government officials.

Stakeholder	Stakeholder Location	Meeting Location	Date
Arco-Butte County Business Incubation Center	Arco, ID	Arco, ID	08/21/2014
Bannock County Commissioners	Pocatello, ID	Arco, ID	2014
Bannock Development Corporation	Pocatello, ID	Arco, ID	08/21/2014
Bingham County Commissioners	Blackfoot, ID	Blackfoot, ID	2014
Bingham Economic Development Corporation	Blackfoot, ID	Blackfoot, ID	2014
Butte County Chamber of Commerce	Arco, ID	Arco, ID	08/21/2014
Butte County Commissioners	Arco, ID	Arco, ID	08/21/2014; 11/09/2015; recurring quarterly briefings
Butte County School District	Arco, ID	Arco, ID	08/21/2014
City of Arco	Arco, ID	Arco, ID	08/21/2014
City of Blackfoot Mayor	Blackfoot, ID	Blackfoot, ID	2014
Clark County Commissioners	Dubois, ID	Arco, ID	08/2014
Congressman Labrador’s staff	Meridian, Lewiston, and Coeur d’Alene, ID; Washington, DC	Boise, ID; Washington, DC	03/17/2015; 02/12/2016
Congressman Simpson and staff	Idaho Falls, ID, Washington, DC	Idaho Falls, ID; Washington, DC	10/17/2012; 05/08/2015; 02/12/2016
David Danielson, Assistant Secretary for the DOE Office of Energy Efficiency and Renewable Energy	Washington, DC	Idaho Falls, ID	10/17/2012; 06/30/2015
DOE-ID	Idaho Falls, ID	Idaho Falls, ID	01/14/2014; 10/13/2015
Eastern Idaho Economic Development Partners	Idaho Falls, ID	Idaho Falls, ID	08/2014
Energy and Geoscience Institute, University of Utah	Salt Lake City, UT	Salt Lake City, UT	03/14/2014;12/02/2014; 04/2/2015
Fort Hall, Shoshone-Bannock Tribal Council	Fort Hall, ID	Fort Hall, ID; Idaho Falls, ID	07/19/2014; 12/16/2014; 02/05/2016
Geothermal Resources Council	Davis, CA	Reno, NV	09/20–24/2015
Grow Idaho Falls, Inc.	Idaho Falls, ID	Idaho Falls, ID	2014
Idaho Clean Energy Association (R. Podgorney now serving on Board of Directors)	Boise, ID	Boise, ID	08/04/2015

Table A-1. (continued).

Stakeholder	Stakeholder Location	Meeting Location	Date
Idaho Conservation League	Boise, Sandpoint, and Ketchum, ID	Boise, ID	03/16/2015; quarterly telephone calls
Idaho Department of Commerce	Boise, ID	Boise, ID	08/2015
Idaho Department of Energy Resources	Boise, ID	Boise, ID; Idaho Falls, ID	07/22/2015;0 9/10/2015; 11/05/2015
Idaho Department of Environmental Quality	Boise, ID	Idaho Falls, ID	07/17/2012
Idaho Department of Transportation	Boise, ID	Field Site, INL, ID	10/09/2015
Idaho Department of Water Resources	Boise, ID	Idaho Falls, ID; Boise, ID	8/06/2014; 09/23/2014; 02/09/2016; quarterly telephone calls
Idaho Falls Power	Idaho Falls, ID	Idaho Falls, ID	08/2015
Idaho Governor and Lieutenant Governor	Boise, ID	Idaho Falls, ID	08/2015
Idaho Joint Finance-Appropriations Committee	Boise, ID	Idaho Falls, ID	10/21/2015
Idaho Science Center	Arco, ID	Arco, ID	08/21/2014
Idaho Technology Council	Boise, ID	Boise, ID	03/10/2014
Idaho Water Users Association	Boise, ID	Sun Valley, ID	06/24/2014
INL Water Group	Idaho Falls, ID	Idaho Falls, ID	05/21/2015
John Kotek, Assistant Secretary for the DOE Office of Nuclear Energy	Washington, DC	Idaho Falls, ID	06/30/2015
Ketchum City Council	Ketchum, ID	Ketchum, ID	05/05/2014; 08/27/2015; 01/8/2016
Lemhi County Economic Development Association	Salmon, ID	Salmon, ID	08/2014
Lost River Economic Development Organization	Arco, ID	Arco, ID	11/09/2015
Montana Department of Environmental Quality	Helena, MT	Idaho Falls, ID	10/21/2015
National Rural Electric Cooperative Association	Arlington, VA	Idaho Falls, ID	5/30/2012
POWER Engineers	Hailey, ID, Boise, ID, and 36 other U.S. locations	Meridian, ID	12/04/2015; 02/05/2016
Premier Technologies	Blackfoot, ID	Blackfoot, ID	12/02/2015
Regional Economic Development for East Idaho	Idaho Falls, ID	Idaho Falls, ID	08/2014
Rocky Mountain Power/PacifiCorp	Portland, OR; Salt Lake City, UT	Rexburg, ID; Salt Lake City, UT	08/21/2014
Senate Energy and Natural Resources Committee staff	Washington, DC	Washington, DC	02/12/2016
Senator Crapo and staff	Idaho Falls, ID, Washington, DC	Washington, DC	06/12/2015; 02/12/2016

Table A-1. (continued).

Stakeholder	Stakeholder Location	Meeting Location	Date
Senator Murkowski and staff	Washington, DC; Fairbanks, Anchorage, Matsu, Ketchikan, Kenai, Juneau, AK	Idaho Falls, ID	03/2015
Senator Risch and staff	Idaho Falls, ID, Washington, DC	Washington, DC	02/12/2016
Senator Sanders's staff	Washington, DC; Burlington and St. Johnsbury, VT	Washington, DC	02/12/2016
Senator Sullivan and staff	Washington, DC; Anchorage, Fairbanks, Juneau, Mat-su Valley, Kenai, Ketchikan, AK	Chena Hot Springs, AK	08/16/2015
Snake River Alliance	Boise, ID	Boise, ID	03/16/2015
Sun Valley Institute for Resilience	Ketchum, ID	Sun Valley, ID	01/08/2016
The Bargain Barn	Arco, ID	Arco, ID	08/21/2014
U.S. Army Corps of Engineers	Washington, DC	Fort Leonard Wood, MO	07/21/2014
U.S. Environmental Protection Agency	Washington, DC	Washington, DC; Idaho Falls, ID; Raleigh, NC; Cincinnati, OH	01/21/2014; 04/01/2014; 05/19/2015
University of Idaho	Moscow, ID	Idaho Falls, ID; Moscow, ID	04/11/2014; 11/17/2015
University of Wyoming	Laramie, WY	Laramie, WY	06/23/2015

Table A-2. Letters of support.

Organization / Entity	Location	Date
Arco-Butte County Business Incubation Center	Arco, ID	September 7, 2014
Bannock Development Corporation	Pocatello, ID	September 10, 2014
Bingham County Commissioners	Blackfoot, ID	September 8, 2014
Bingham Economic Development Corporation	Blackfoot, ID	September 4, 2014
Brett Holist, Maintenance, City of Arco	Arco, ID	August 26, 2014
Butte County Chamber of Commerce	Arco, ID	September 7, 2014
Butte County Commissioners	Arco, ID	September 9, 2014
Butte County School District Superintendent Spencer Larsen	Arco, ID	August 27, 2014
Clark County Idaho Board of County Commissioners	Dubois, ID	2014
Clay Condit, Idaho Science Center	Arco, ID	August 23, 2014
Eastern Idaho Economic Development Partnership	Blackfoot, ID	August 25, 2014
Erv Grafwallner, Council Member, City of Arco	Arco, ID	August 26, 2014
Fort Hall Business Council	Fort Hall, ID	August 29, 2014
Gene Davis, Council President, City of Arco	Arco, ID	August 26, 2014
Grow Idaho Falls, Inc.	Idaho Falls, ID	September 16, 2014
Idaho Clean Energy Association	Boise, ID	September 2, 2014
Idaho Governor C.L. “Butch” Otter	Boise, ID	August 26, 2014
Jackie Flowers, General Manager, Idaho Falls Power	Idaho Falls, ID	September 9, 2014
Kim Sanders, Maintenance, City of Arco	Arco, ID	August 26, 2014
Lemhi County Economic Development Association	Salmon, ID	September 5, 2014
Lost Rivers Economic Development	Arco, ID	August 23, 2014
Mayor Paul M. Loomis, City of Blackfoot	Blackfoot, ID	September 9, 2014
Mayor Ross Langseth, City of Arco	Arco, ID	August 26, 2014
Otto J. Higbee, Board Member of Lost Rivers Economic Development	Mackay, ID	September 5, 2014
Small Business Owner: Rosanne Barnal, The Bargain Barn	Arco, ID	2014
Tony Chisham, Maintenance Supervisor, City of Arco	Arco, ID	August 26, 2014
Travis Gilchrist, Council Member, City of Arco	Arco, ID	August 26, 2014
University of Idaho Extension Professor Charles C. Cheyney	Arco, ID	September 7, 2014
Virginia Parsons, City Clerk/Treasurer	Arco, ID	August 26, 2014

Table A-3. Table of previous and planned presentations at professional meetings.

Technical Meetings and Events

Meeting / Event	Presentation Title	Authors
Stanford Geothermal Workshop, Palo Alto, CA (January 2015)	Geothermal Play Fairway Analysis of the Snake River Plain, Idaho	D.L. Nielson, J. Shervais, L. Liberty, S.K. Garg, J. Glen, C. Visser, P. Dobson, E. Gasperikova, E. Sonnenthal
Stanford Geothermal Workshop, Palo Alto, CA (January 2015)	He Isotopic Evidence for Undiscovered Geothermal Systems in the Snake River Plain	P.F. Dobson, B.M. Kennedy, M. Conrad, T. McLing, E. Mattson, T. Wood, C. Cannon, R. Spackman, M. Van Soest, M. Robertson
World Geothermal Conference, Australia (April 2015)	Geothermal Reservoir Temperatures in Southeastern Idaho, USA, Using Multicomponent Geothermometry	Ghanashyam Neupane, Earl Mattson, Travis McLing, Carl Palmer, Robert Smith, Thomas Wood, Robert Podgorney
World Geothermal Conference, Australia (April 2015)	Modeling of Propagations of Interacting Cracks under Hydraulic Pressure Gradient	Hai Huang, Earl Mattson, Robert Podgorney
Snake River Geothermal Workshop, Idaho Falls, ID (July 2015)	Various	Robert Podgorney, Thomas Wood, Mike McCurry, Roy Mink, Bill Hackett, Carl Palmer, John Welhan, Dario Grana, Suzette Payne
Geothermal Energy Expo, Reno, NV (September 2015)	Workshop Reservoir Stimulation: Recent Field Practices, Monitoring Techniques, and Theoretical/ Laboratory Investigations Informational Booth	Ahmad Ghassemi
Water-Energy Nexus Forum, Layton, UT (January 2016)	Panel Session: Meeting the Water and Energy Challenge Informational Booth	Travis McLing
CAES Seminar (January 2016)	Learn about FORGE Team Member Campbell Scientific Instrumentation and Measurement Tools	Dirk V. Baker
CAES Geofluids Seminar (January 2016)	Topographic Stress Controls on Bedrock Weathering Revealed by Geophysical Imaging	James St. Clair
CAES Geofluids Seminar	Some Like it Hot: Mass and Heat Transfer in the Yellowstone Caldera, Wyoming	Jerry Fairley
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	The DOE Geothermal Data Repository and the Future of Geothermal Data	Jon Weers, Arlene Anderson
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	A Snake River Plain Field Laboratory for Enhanced Geothermal Systems: An Overview	Robert Podgorney, Neil Snyder, Roy Mink, Travis McLing

Table A-3. (continued).

Meeting / Event	Presentation Title	Authors
	of the Snake River Geothermal Consortium's Proposed FORGE Approach and Site	
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Using Gravity and Magnetics to Delineate Structural Controls on Geothermal Fluids, Northern Cache Valley, Idaho	Wade Worthing, Tom Wood, Jonathan Glen, Travis McLing, Pat Dobson, Brent Ritzinger, Ghanashyam Neupane, Michael Thorne
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Thermal and Geochemical Anomalies in the Eastern Snake River Plain Aquifer: Contributions to a Conceptual Model of the Proposed FORGE Test Site	John Welhan
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Geomechanical Characterization of Rock Core from the Proposed FORGE Laboratory on the Eastern Snake River Plain, Idaho	Rohit Bakshi, Ahmad Ghassemi, Mostafa Eskandari Halvaei
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Rock Physics Modeling for the Potential FORGE Site on the Eastern Snake River Plain, Idaho	Dario Grana, Sumit Verma, Robert Podgorney
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Geothermal Play Fairway Analysis of the Snake River Plain: Phase 1	John W. Shervais, Jonathan M. Glen, Dennis Nielson, Sabodh Garg, Patrick Dobson, Erika Gasperikova, Eric Sonnenthal, Charles Visser, Lee M. Liberty, Jacob Deangelo, Drew Siler, James P. Evans
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Seismic Characterization of the Newberry and Cooper Basin EGS Sites	Dennise Templeton, Jingbo Wang, Meredith Goebel, Gardar Johannesson, Stephen Myers, David Harris
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Long-term Sustainability of Fracture Conductivity in Geothermal Systems Using Proppants	Earl D. Mattson, Ghanashyam Neupane, Mitchell Plummer, Clay Jones, Joe Moore
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Mixing Effects on Geothermometric Calculations of the Newdale Geothermal Area in the Eastern Snake River Plain, Idaho	Ghanashayam Neupane, Earl D. Mattson, Cody J. Cannon, Trevor A. Atkinson, Travis L. McLing, Thomas R. Wood, Wade C. Worthing, Mark E. Conrad
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Gigawatt-Scale Power Potential of a Magma-Supported Geothermal System in the Fold and Thrust Belt of Southeast Idaho	John Welhan
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Application of Isotopic Approaches for Identifying Hidden Geothermal Systems in Southern Idaho	Mark Conrad, Patrick Dobson, Eric Sonnenthal, B. Mack Kennedy, Cody Cannon, Wade Worthing, Thomas Wood,

Table A-3. (continued).

Meeting / Event	Presentation Title	Authors
		Ghanashyam Neupane, Earl Mattson, Travis McLing
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Potential Hydrothermal Resource Areas and Their Reservoir Temperatures in the Eastern Snake River Plain, Idaho	Ghanashayam Neupane, Earl D. Mattson, Cody J. Cannon, Trevor A. Atkinson, Travis L. McLing, Thomas R. Wood, Wade C. Worthing, Patrick F. Dobson, Mark E. Conrad
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	An Assessment of Some Design Constraints on Heat Production of a 3D Conceptual EGS Model Using an Open-Source Geothermal Reservoir Simulation Code	Yidong Xia, Mitch Plummer, Robert Podgorney, Ahmad Ghassemi
Stanford Geothermal Workshop, Palo Alto, CA (February 2016)	Geologic Setting of the Idaho National Laboratory Geothermal Resource Research Area	Michael McCurry, Travis McLing, Richard Smith, William Hackett, Ryan Goldsby, William Lochridge, Robert Podgorney, Thomas Wood, David Pearson, John Welhan, Mitch Plummer
GEA US & International Geothermal Showcase, Washington, DC (March 2016)	Water Purification Driven by Geothermal Heat, a Novel Treatment Process under Development and Supported by DOE	Robert Podgorney
Presentation to DOE-ID, Idaho Falls, ID (May 2016)	SRGC FORGE Update	Robert Podgorney
GEA National Geothermal Summit, Reno, NV (June 2016)	TBD	TBD
2nd Snake River Geothermal Workshop: Reservoir Creation in Igneous Rocks, Idaho Falls, ID (August 2016)	TBD	TBD

Non-Technical Meetings and Events

Event	Location	Date
10th Annual Renewable Energy Fair	Chena Hot Springs, AK	08/16/2015
Idaho Joint Finance-Appropriations Committee Event	Idaho Falls, ID	10/21/2015
National Renewable Energy Laboratory Coffee Break Presentation: A Snake River Plain Field Laboratory for Enhanced Geothermal Systems	Golden, CO	01/21/2016
Planet Jackson Hole reporter Natosha Hoduski	Idaho Falls, ID	03/01/2016
TEDx Talk (TEDxIdahoFalls)	Idaho Falls, ID	04/02/2016

Table A-3. (continued).

Event	Location	Date
Geothermal Energy Presentation to Water Springs Junior High and High School	Idaho Falls, ID	04/14/2016
Idaho Falls Earth Day Booth	Idaho Falls, ID	04/23/2016
Geothermal Energy Presentation to Idaho Falls High School Power and Energy Class	Idaho Falls, ID	04/28/2016
Open House/EGS Event	Idaho Falls, ID	Summer 2016
Media Site Tour	INL Site, ID	August 2016