**Department of Energy**
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Golden, Colorado 80401

July 1, 2014

Carol Benkosky
Prineville District Manager
Prineville District – Bureau of Land Management
3050 NE Third Street
Prineville, OR 97754

SUBJECT: Approval of Induced Seismicity Mitigation Plan (ISMP) edits associated with Department of Energy (DOE) Award Number DE-EE0002777, *Recovery Act: Newberry Volcano EGS Demonstration*

Dear Ms. Benkosky,

This letter is meant to inform the Prineville District that DOE has approved the attached ISMP appendix (Appendix "J") associated with the Newberry EGS demonstration project.

On April 14, 2014 DOE held the second of four "Stage Gate" reviews associated with the Newberry project. During this review meeting and in the weeks following, throughout which the discussion continued, three potential amendments to the original ISMP were discussed amongst AltaRock, DOE, the DOE appointed Stage Gate Review Team, and the DOE Technical Monitoring Team.

Based on the fact that NWG 55-29 did not develop a positive well head pressure, AltaRock proposed a reduction in the amount of empty sump capacity required in the original ISMP. The DOE Stage Gate Review Team and Technical Monitoring Team suggested that additional field calibrated modeling would be necessary to determine a theoretical potential for flowback from the well under several possible conditions, because the lack of wellhead pressure and inability of NWG 55-29 to flow was likely attributable to the casing leak rather than the reservoir character. AltaRock and Lawrence Berkeley National Laboratory developed and ran a range of modeled scenarios to determine the necessary flowback storage capacity required during the stimulation. The modeling results indicate that a flowback storage capacity of 5% should be sufficient, and that "constructing a pipeline for restimulating well NWG 55-29 in 2014 is neither necessary nor cost effective."

The second amendment to the ISMP will require that additional information is shared in the daily seismicity reports that DOE, BLM, FS and other involved parties receive from AltaRock during the stimulation. Since 2011 when the ISMP was developed and signed, seismologists have identified additional parameters that are considered indicators of seismic risk or seismogenic potential. One such indicator is based on the relationship between the cumulative injected volume of fluid and the cumulative seismic moment, which correlates with the largest induced event that may occur at a given site. Going forward, AltaRock's seismicity report will track injected volume and seismic moment data on a daily basis. Based on the recommendation from renowned seismologist Dr. Ernest Majer, the daily seismicity report will also include another new chart that plots b-value vs. time. A reduction in the b-value indicates that higher magnitude events are occurring with greater frequency or at a higher rate, and can serve as an indicator of seismic risk.

The final amendment to the ISMP consists of edits to the contact information listed in the original document. Details can be found in the attached appendix.

This letter constitutes written acknowledgement that the proposed amendments to AltaRock Energy Inc.'s Newberry Induced Seismicity Mitigation Plan (ISMP), detailed in Appendix J, have been deemed technically acceptable by DOE, the DOE Stage Gate Review Team and Technical Monitoring Team.

Please feel free to contact the DOE Project Officer, Lauren Boyd, at (202) 287-1854 to discuss these modifications or any other matters relevant to the Newberry EGS demonstration, at your convenience.

Best Regards,

Michael A. Buck

Michael A. Buck
DOE Contracting Officer

# Appendix J: Proposed Amendments to Induced Seismicity Mitigation Plan

## Background

In Phase 1 of the Newberry EGS Demonstration an Induced Seismicity Mitigation Plan (ISMP) was developed and incorporated into the BLM's Environmental Assessment (BLM, 2012) and the DOE award documents. The full ISMP is also available on AltaRock's website (AltaRock, 2011a, 2011b). Based on the results of the 2012 stimulation, three amendments to the ISMP are proposed here:

1. A change in the amount of empty sump capacity required and new pressure bleed off guidelines.
2. The addition of two new graphs to the seismicity reports.
3. Updates of the contact information for induced seismicity communications.

## Sump Capacity Change

The controls and guidelines developed for the ISMP were based on the analysis of the Newberry site-specific geologic and environmental conditions, and lessons learned from other EGS sites. A lesson learned from the Deep Heat Mining (DHM) project in Basel, Switzerland was related to flow-back to relieve reservoir pressure after a potentially damaging microseismic event. At Basel, injection resulted in a positive well head pressure after the pumps were turned off and relieving that pressure by allowing flow-back resulted in an immediate stop to microseismic events. Based on the Basel experience, a 2.5 mile long, temporary pipeline was constructed to connect the 55-29 pad to the 46-16 sump and provide a total of 2.8 million gallons of sump capacity, or more than 10% of the planned injection volume of 24 million gallons. Renting the pipeline and pumps as well as the labor to install and remove the pipeline was a significant cost and effort (Section 2.8).

## Flow Back Simulations

One result of the 2012 stimulation at Newberry was that a positive well head pressure did not develop. Rather, well head pressure quickly dropped to zero once the injection pumps were shut off, and well head pressure remained negative for several weeks thereafter. The field-data-calibrated THM model described in Section 4.2 of the main report was used to test the theoretical potential for flowback from well NWG 55-29 under several different possible post-stimulation conditions.

Figures J-1, J-2, and J-3 illustrate the range of modeled stimulation scenario results. In the first, pore compressibility increased ten-fold with no change in reservoir permeability by injecting 2.9 x $10^6$ gallons of water at 96 gpm over 21 days. The well then flowed back 135,000 gallons, or 4.7%, over nine days. Such an increase in compressibility without a corresponding increase in permeability is not a realistic scenario and thus considered a worst case. In the second scenario, permeability was increased seven-fold ($k_x$=3.5e$^{-17}$ m$^2$, $k_y$=$k_z$=7.e$^{-17}$ m$^2$) by injecting 4.85 x $10^6$ gallons of water at a rate of 170 gpm over 21 days. The well then flowed back only about 56,000 gallons, or 1% of the total injection volume, over six days. In the third case, the simulation continued much longer, for 56 days in order to reach a volume nearer the injection goal of 20 million gallons. In this case, the cooling of the rock mass caused even less flow back than the 21 day scenarios. Therefore, the modeling results indicate that a revised a well pad flowback storage capacity of 5% will be sufficient, and that constructing a pipeline for restimulating well NWG 55-29 in 2014 is neither necessary nor cost effective.

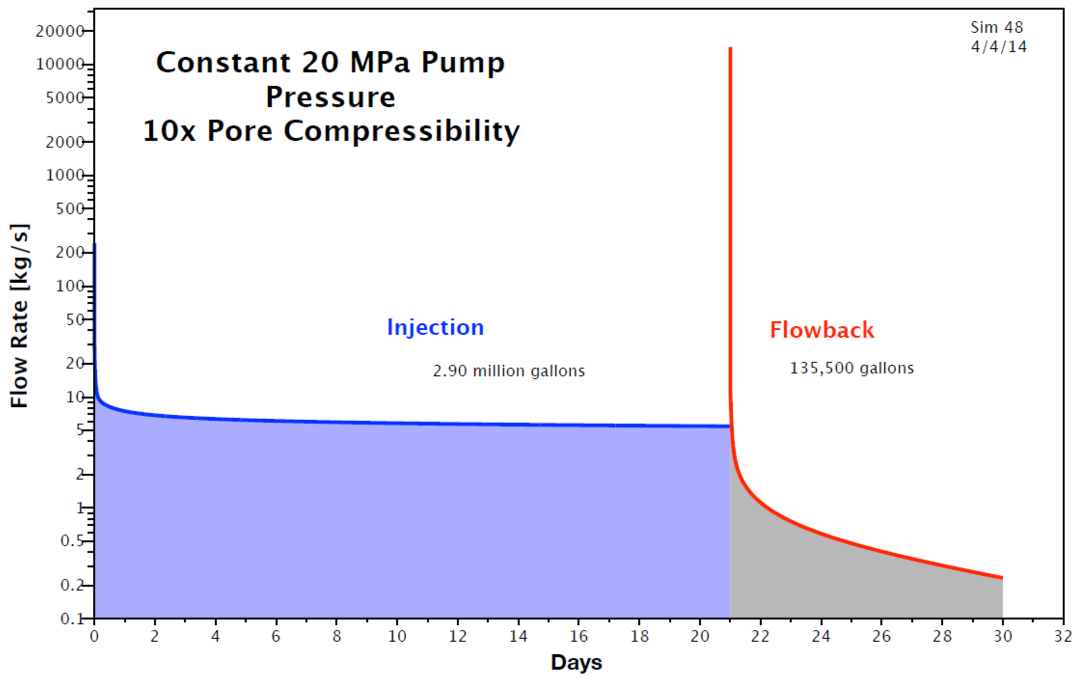


**Figure J-1. Worst case modeled stimulation and flowback of well NWG 55-29, 10-fold increase in pore compressibility. Blue = injection period, red = flowback period.**

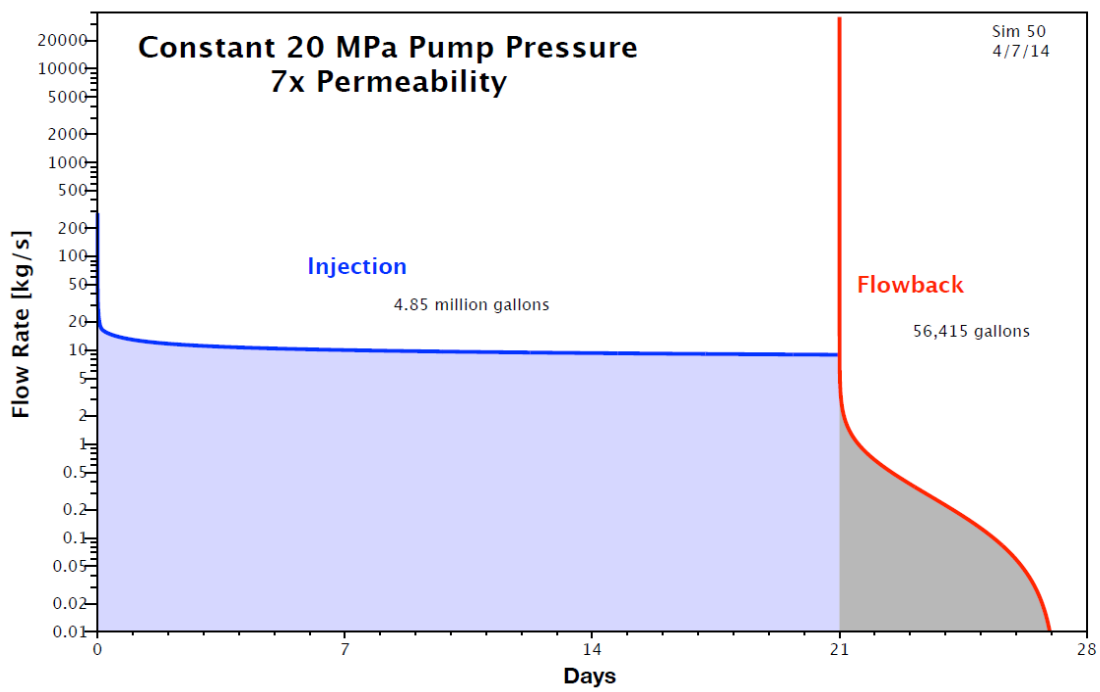


**Figure J-2. Best case modeled stimulation and flowback of well NWG 55-29, 7-fold permeability increase. Blue = injection period, red = flowback period.**

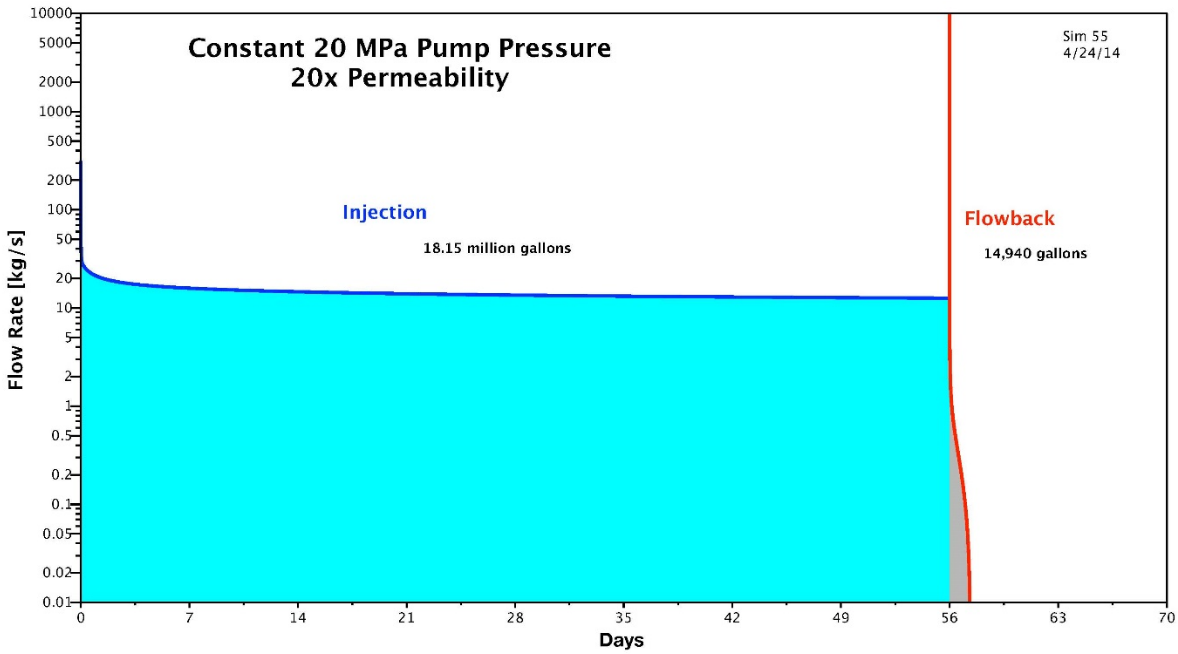


**Figure J-3. Modeled stimulation to inject ~20 million gallons and flowback of well NWG 55-29, 20-fold permeability increase. Blue = injection period, red = flowback period.**

## Pressure bleed-off during shut-in

After shut-in in 2012, the well head pressure dropped to 50% of the shut-in pressure in 19 minutes and 75% in 66 minutes. The well head pressure was 0 in just 16 hours. The pressure fall-off is expected to be more gradual after re-stimulation in 2014; however, if pressure remains high after shut-in, this could result in increased seismicity and increased chance of larger (M >2.0) seismic events. Therefore, as an extra precaution, we will bleed-off the fluid pressure to 50% of the initial shut-in pressure if it does not reach that value on its own within 12 hours. Furthermore, if, during the shut-in period, an M>2.7 event occurs, and well head pressure has not dropped to 10% of the initial shut-in pressure, it will be bled-off to 10%. After the cold injected water has time to heat up, the well head pressure should begin to rise again as a gas cap forms. Once the well head pressure builds back up to 1000 psi due to heat up, the well will be ready to flow

## Additions to Seismicity Report

During the 2012 stimulation, the microseismic array (MSA) was used to constantly monitor the characteristics of induced microseismicity and growth of the EGS reservoir during hydroshearing operations. At the operational office located at the well site, project geoscientists monitored and compared the injection rate, wellhead pressure, event locations, maximum event size, the size distribution of microseismicity (the b-value), and other parameters.

When microseismicity was being induced by the stimulation, a seismicity report was prepared and emailed to representatives of the DOE, BLM, FS, PNSN and LBNL. All of these seismicity reports are provided in Appendix D. Each report contained graphs showing the well head pressure and flow rate versus time, compared to microseismic event times. Map view and cross-sectional views of the events were also provided.

Since the original ISMP was written, additional tracking parameters has been developed to monitor for changes in seismic risk. For example, McGarr (2014), showed the relationship between seismic moment of the largest induced event (or cumulative seismic moment) and cumulative injected volume (Figure J-

4). The $M_0$=GΔV line in Figure J-4 is an upper bound to the relationship between injected volume and seismic response. This analysis shows that, compared to other injection projects, the seismicity induced during the Newberry EGS demonstration in 2012 is far from the $M_0$=GΔV boundary, indicating a low seismogenic potential. This graph provides an empirical and theoretical basis for judging the potential for induced seismic events which might be felt. Therefore, a version of this graph, updated with the cumulative volume and both cumulative and maximum moment will be included in the regular seismicity reports.

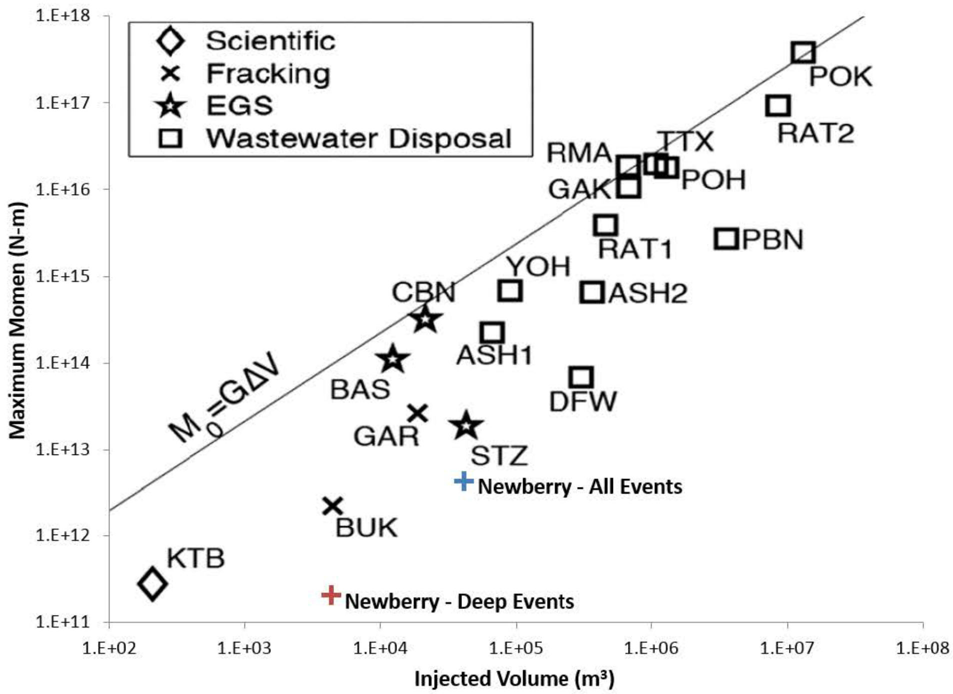


**Figure J-4. Comparison of Injected Volume to Maximum Moment for various injection projects (McGarr, 2014) with Newberry EGS seismicity data overlain. This figure is also shown and discussed as Figure 5-22 in main text.**

Another technique developed since the original ISMP was written is tracking of the temporal evolution of the b-value of the Gutenberg-Richter relationship. A reduction in the b-value will indicate that seismic events with relatively larger magnitudes are occurring at a higher rate. The best way to track evolution of the b-value is to use a sliding window of at least 100 of the most recent seismic event magnitudes. A b-value vs. time chart will also be included in the seismicity reports as soon as a catalog of about 100 events with acceptable quality magnitudes is developed.

Neither of the proposed new seismic risk tracking parameters have been used during an EGS stimulation to inform operational parameters. Providing this information to the seismic reviewers (seismologists at PNSN, LBL, and DOE) on a regular basis will allow further evaluation on the use of these parameters to quantify evolving seismic risk. If an increasing seismic risk is suggested by analysis of either data set, a discussion with the seismic reviewers will be initiated. Factors such as the quality of the data set, the rate of change of the seismic risk and what proactive measures might be taken to lower the seismic risk will be taken into consideration. If the seismic team concludes that an unacceptable seismic risk has developed and that the risk can be lowered by mitigative actions such as lowering the well head pressure and flow rate, AltaRock, with concurrence from the DOE, will undertake these actions.

## ISMP Amendments

The following highlighted edits are proposed for the ISMP, including an update of contact information:

**Proposed edits to Page 12 to update Toll Free Number (original number was lost):**

Two web sites, several social media outlets, and a toll-free telephone line (1-844-EGS4USA) have been established to promote Demonstration communication.

**Proposed edits to Page 35:**

As shown at the top panel in Figure 3-8 the flow-back at Basel was initially as high as 1000 L/m (~250 gpm), about 25% of the injection rate, which caused an immediate stop to the microseismic events M > 2.0. In the first day of flow-back about 10% of the injected fluid returned. Eventually, over the next 14 months, a total of about 30% (900,000 gallons) of the injected fluid flowed back (Häring et al., 2008). **DELETE:** ~~After hydroshearing is completed at the Newberry EGS Demonstration, we plan to immediately flow back the injected water to relieve reservoir pressure and mitigate continued fracture growth and induced seismicity. Based on the Basel experience, we plan to keep sufficient room in sumps to hold at least 10% of the volume injected in any stage. Accordingly, two sumps with a combined capacity of about 3,000,000 gallons will be available, sufficient to contain 12% of the maximum water use estimated for single-well stimulation over a 21-day period.~~ **REPLACE WITH:** During the Newberry EGS Demonstration stimulation in 2012, AltaRock kept sufficient room in the well pad sumps to hold at least 10% of the injected volume for potential flow back. This volume was selected based on experiences at the Basel project. Having this storage volume required a 2.5 mile long temporary pipeline be constructed to connect the 55-29 pad to the 46-16 sump and provide a total of 2.8 million gallons of sump capacity, or more than 10% of the planned injection volume of 24 million gallons. One result of the 2012 stimulation at Newberry was that positive well head pressure did not develop. Instead, well head pressure rapidly dropped to zero once the injection pumps were shut off, and well head pressure remained negative for several weeks thereafter. A thermal-hydrological-mechanical (THM) model was developed and calibrated using the results of the 2012 stimulation. The model was used to simulate the theoretical potential for flowback from well NWG 55-29 under a range of possible post-stimulation conditions. A conservative estimate of the usable dimensions of the S-29 pad sump is 133x16x2.5m, for an estimated volume of 5300m$^3$ or 1.4 million gallons. The northern half of the sump, which will be used for water supply, is about 30% of the total volume, or roughly 400,000 gallons. This leaves a capacity of at least 1 million gallons in the southern part of the sump for emergency flow back water. Therefore, even under unrealistically conservative conditions, the modeling results indicate that a revised well pad flowback storage capacity of 5% will be sufficient, and that constructing a pipeline for restimulating well NWG 55-29 in 2014 is neither necessary nor cost effective.

**Proposed edits to Page 43:**

The MSA will be used to constantly monitor the growth of the EGS reservoir during hydroshearing operations. At the operational center located near the well site, seismologists and engineers will be monitoring and comparing the injection rate, wellhead and downhole pressure, event locations, maximum event size, the size distribution of microseismicity (the b-value), cumulative injected volume, cumulative seismic moment, and other parameters 24 hours a day.

The Project Manager will ensure that a daily activity report is transmitted to the DOE, BLM, FS, PNSN and LBNL. The daily report will be accompanied by several graphs including surface pressure, bottom hole pressure and flow rate versus time, and temperature versus depth. The daily seismicity graphic will show events versus depth and distance from the well. The events will be color-coded to differentiate recent and older events, and size-coded to delineate event magnitude. The report will include a graph which shows the b-value calculated from the last 100 events so that a systematic change in B-value can be visualized. The report will also include graph of total injected volume vs cumulative seismic moment and maximum seismic moment (i.e. the McGarr graph). These reports will be transmitted to designated third parties (e.g., DOE and BLM) by 11:00 am each day. If an increasing seismic risk is suggested by analysis of b-value or McGarr graphs, a discussion with the seismic reviewers will be initiated. Mitigative action will be taken if responsible parties agree it is warranted.

**Proposed edits to Page 49:**

**7. Stop Injection and Flow Well** – Any ground motion recorded on the Paulina Lake SMS with a PGA greater than 0.028 g that can be correlated in time to a seismic event within the 3 km (1.9 mi) aperture of the MSA will result in injection being halted. In addition, any seismic event detected within the 3 km (1.9 mi) aperture of the MSA with M greater than 3.5 as determined by PNSN or the AltaRock MSA, will also result in injection being halted. After injection is stopped, the well will be immediately flowed to surface test equipment to relieve reservoir pressure (see Section 4.6). Sufficient sump capacity will be available to store at least ~~10%~~ 5% of the injected fluid. Resumption of stimulation will be made only after consultation and agreement between AltaRock, DOE, BLM and FS.

**8. Bleed-off during shut-in** – After the well is shut-in, it is expected that the well head pressure will drop rapidly on its own. To reduce the probability of post-stimulation induced seismicity caused by fluid overpressure, the well will be bled-off to 50% of the initial shut-in pressure if it does not reach that value on its own within 12 hours. Furthermore, if, during the shut-in period, an M>2.7 event occurs, and well head pressure has not dropped to 25% of the initial shut-in pressure, it will be bled-off to 25%. After the cold injected water has time to heat up, the well head pressure should begin to rise again as a gas cap forms. If the well head pressure builds back up to 50% of the shut-in pressure due to heat up and development of a gas cap, the well will be opened up and the flow test begun. If well head pressure does not build back up to this value, other criteria will be used to determine when to start the flow test.

**Proposed edits to Page 43 to update Contacts:**

Table 4-3. Updated Contacts for Induced Seismicity Communications

| Organization | Contact Name | Email Address | Phone |
|---|---|---|---|
| Technical Notification and Review: Outlier, Trigger, and Mitigation Reports | | | |
| Pacific Northwest Seismic Network (PNSN) | John Vidale | john_vidale@mac.com | (206) 543-6790 |
| U.S. Department of Energy (DOE) | Lauren Boyd | Lauren.Boyd@go.doe.gov | (202) 297-8798 |
| Lawrence Berkeley National Lab (LBNL) | Ernest Majer | elmajer@lbl.gov | (510) 486-6709 |
| U.S. Bureau of Land Management (BLM) | Steve Storo | steve_storo@blm.gov | (541) 295-0871 |
| U.S. Forest Service (FS) | Barton Wills | bwills@fs.fed.us | (541) 480-6194 |
| Emergency Notification: Seismic Event Reports | | | |
| Deschutes County Sheriff | Dispatch | NA | **(541) 693-6911** |

**Proposed edits to Page 52 to update Toll Free Number (original number was lost):**

- Signs will be posted at the beginning of Road 500 for uphill traffic, and on Paulina Peak for downhill traffic, stating "Rock fall hazard ahead. Please contact 844-USA-4-EGS toll-free (844-347-4872) to report rocks on the road," or alternative text approved by the FS. ….
- Signs will be posted at snow parks and other entrance points that provide winter access to NNVM. The signs will read "Warning: snow avalanche hazards exist on any slope steeper than 25°, including the slopes leading to Paulina Lake and East Lake from the Crater Rim. Skiers and snowmobilers, and geothermal demonstration activities occurring this winter can trigger avalanches on hazardous slopes. Call 844-USA-4-EGS toll-free (844-347-4872) for more information", or alternative text approved by the FS……

## References

AltaRock (2011a), Induced Seismicity Mitigation Plan, Newberry EGS Demonstration. Posted August 2011, 3 MB, http://altarockenergy.com/projectupdates/Newberry_ISMPlan.pdf

AltaRock (2011a), Induced Seismicity Mitigation Plan, Newberry EGS Demonstration. Posted August 2011, full version with appendices 60 MB, http://altarockenergy.com/projectupdates/Newberry%20EGS%20Demonstration%20ISMP%203Aug11.pdf

BLM, 2012, Environmental Assessment for Newberry Volcano Enhanced Geothermal System (EGS) Demonstration Project, Decision Record April 5, 2012, http://www.blm.gov/or/districts/prineville/plans/newberryegs/index.php

McGarr, A. 2014. Maximum magnitude earthquakes induced by fluid injection. Journal of Geophysical Research: Solid Earth, 119.