

Utah FORGE Traffic Light System (Version 2)

The following is the Traffic Light System (TLS) for Utah FORGE that will be followed for all field operations on the FORGE location. All personnel involved in field activities should be familiar with the system. The ultimate goal of the Utah FORGE TLS is to mitigate the seismic response and risk resulting from Enhanced Geothermal System (EGS) operations. At Utah FORGE we define the risk as effects from ground shaking from moderate to large seismic events and risks associated with public perception to EGS.

This system is based on experiences gained from the stimulation of 58-32 and two stimulations and a circulation in 16A(78)-32. In addition, a commercial EGS facility is being established on leases adjacent to the Utah FORGE facility, Cape Station (Fervo). The four Cape Station horizontal wells involved in the 2024 stimulation and circulation terminate at the Utah FORGE lease boundary (< 2000') from 16(A)78-32. Operations at Cape Station have incorporated larger injected volumes and rates than have been pumped at Utah FORGE and the seismic response has been more significant--more seismic events and larger magnitudes, including $M > 2$ events (**Figure 1**). Because of the close proximity, the original Utah FORGE TLS would shut down operations at Utah FORGE for TLS alarm events occurring within Cape Station. Note the number of consecutive days that Cape Station exceeded the $10 M \geq 1$ events threshold (Figure 1). The Cape Station TLS uses an Amber threshold of $M \geq 2$ and a Red threshold of $M \geq 3$, but operational actions differ between operations. It is unclear what their distance thresholds are. Given the much smaller rates and volumes being injected at Utah FORGE, changing operations in the Utah FORGE reservoir is not expected to affect the seismic response within the Cape Station reservoir. There is currently no evidence for a hydraulic connection between the two reservoirs based on available data. However, we are always mindful of public perception and in some cases we must cease operations for this reason.

Summary of Changes

TLS Structure

To implement the changes detailed below, the Utah FORGE TLS table has been split into two tables one for time periods of Utah FORGE Stimulation and Circulation (Table 1) and the second for Utah FORGE Non- Stimulation and Circulation (Table 2), each containing actions to be taken in case of seismic events within the Utah FORGE reservoir or outside of it.

Amber

- Thresholds will be based on location relative to the Utah FORGE reservoir. For the purposes of this document, the reservoir is defined by the extent of the seismic cloud from the 2024 stimulation. **Figure 2** shows that the automatic quasi-real-time monitoring system implemented at Utah FORGE using the detection toolbox *qseek* (Isken et al., 2024) and the local (surface and shallow borehole) network put in place for monitoring during operations (Niemz et al., 2024; Niemz et al., in preparation) can distinguish between events in the Utah

FORGE reservoir and those in the Cape Station reservoir. In the case that there is ambiguity in the location, Utah FORGE will proceed as if the event located within the Utah FORGE reservoir.

- The criterion of $10 M \geq 1$ events in 24 hours represents a threshold only if the events are occurring within the Utah FORGE reservoir.
- The criterion of $10 M \geq 1$ in 24 hours and the events propagating along an imaged fault plane will be treated as adaptive features within this TLS (Table 1). By adaptive, we mean that operations will be modified instead of ceasing operations. For example in the previous TLS, when encountering $10 M \geq 1$ events, Utah FORGE would have proceeded to controlled shut-in; now injection will be decreased by 10%.
- There has been a deeper zone of seismic activity activated by Cape Station operations. If we see larger $M \geq 2$ events in clusters suggesting a planar structure, we will respond in the same manner as an event occurring within the Utah FORGE reservoir.
- If there have been TLS threshold events in the Cape Station immediately prior (up to 48 hours) to operational activities at Utah FORGE, Utah FORGE will follow the TLS for Actions During Utah FORGE Stimulation and Circulation (Table 1).

Red

- The TLS threshold region of 15 km has been reduced to 5 km. An $M > 3$ event within this region will result in Utah FORGE ceasing operations, consulting with DOE and potentially rigging down. As this threshold was originally designed to help with public perception, for events between 5 and 15 km UUSS will issue a press release to provide context for these events relative to Utah FORGE and EGS activities. A template for this text is appended at the end of this document.

References:

Isken, M., P. Niemz, J. Münchmeyer, S. Heimann, S. Cesca, T. Dahm (2024) Qseek: A data-driven Framework for Machine-Learning Earthquake Detection, Localization and Characterization, In revision. Seismica. Code available at <https://pyrocko.github.io/qseek>

Niemz, P., McLennan, J., Pankow, K. L., Rutledge, J., & England, K. (2024). Circulation experiments at Utah FORGE: Near-surface seismic monitoring reveals fracture growth after shut-in. *Geothermics*, 119, 102947.

Niemz, P., Pankow, K. L., Isken, M., Whidden, K., McLennan, J., and Moore, J. (2024). Nodal patch monitoring for improved surface monitoring during Utah FORGE 20024 stimulation [Working title]. In prep.

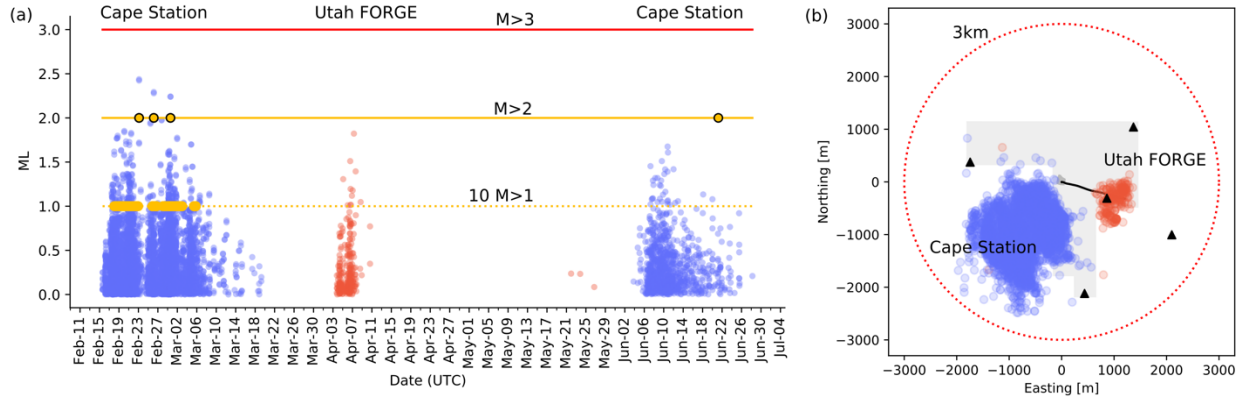


Figure 1. (a) Magnitude time history determined from the Utah FORGE *qseek* (Isken et al., 2024; Niemz et al., in prep.) catalog ($M > 0$) for the time periods of stimulation at Cape Station (blue, February and June 2024) and Utah FORGE (red, April 2024). Yellow circles, indicate TLS thresholds exceeded. (b) Epicentral map, showing the clear clustering of events by operation.

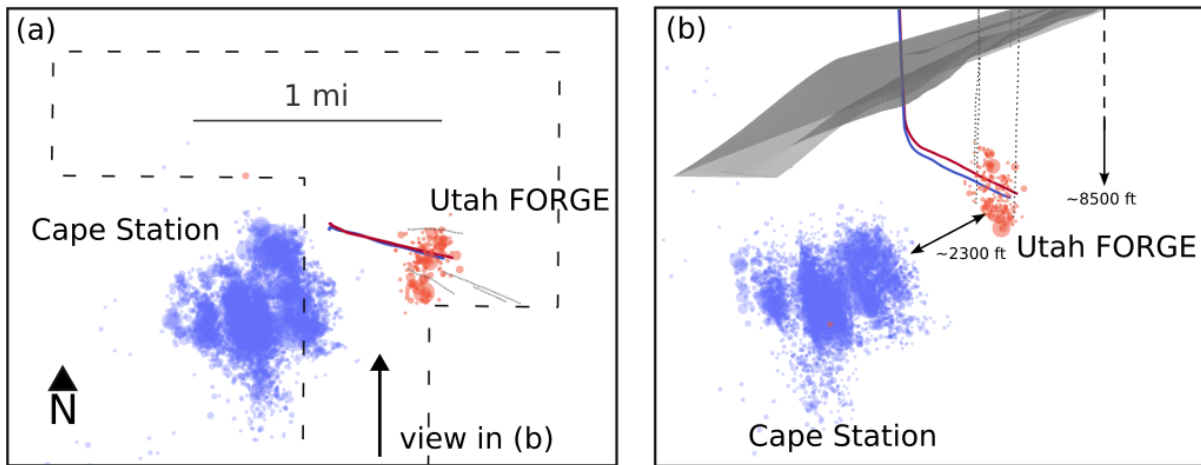


Figure 2. (a) Map and (b) Cross-section showing the automatic locations for 2024 events during Utah FORGE (April 2024, red) and Cape Station stimulations (February and June 2024, blue) determined for seismic events $M > 0$ detected and located with *qseek* (Isken et al., 2024) as implemented at UUSS. Symbol size is scaled by magnitude. Gray surface indicates the top of the basement, red and blue lines, locations of 16B(78)-32 and 16A(78)-32, respectively, and dashed box the original Utah FORGE polygon.

Table 1: Actions During Utah FORGE Stimulation and Circulation

Observations	Actions: UT FORGE Reservoir	Actions: Not UT FORGE Reservoir
<ul style="list-style-type: none"> • No anomalous seismic events 	<ul style="list-style-type: none"> • No actions, Follow good engineering and safety practices 	<ul style="list-style-type: none"> • No actions, Follow good engineering and safety practices
<ul style="list-style-type: none"> • 10 $M \geq 1$ in 24 hr within 3 km • Events propagating along an imaged fault plane 	<ul style="list-style-type: none"> • Notify WSM,¹ Operations Superintendent and Project Manager. The WSM will coordinate appropriate activities on location • If the 10 events locate within a single stimulation zone or if circulating a stimulation defined by the microseismic activity of previous injections: <ul style="list-style-type: none"> ○ Open shut-in wells ○ Step down injection by 10% and hold as appropriate. If seismicity returns to <i>Green</i> threshold values return to operational plan. If not, step down injection again and re-evaluate. • If events occur along an imaged fault plane: <ul style="list-style-type: none"> ○ Initiate controlled flowback in an orderly and controlled fashion. ○ <i>Operations cease until a new plan to continue is developed and approved by the key STAT representatives and DOE</i> 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The WSM will coordinate appropriate activities on location • For 10 events not in the Utah FORGE reservoir, proceed with current operations • For events along an imaged fault plane at reservoir depths not in the Utah FORGE reservoir, proceed with current operations
<ul style="list-style-type: none"> • $M \geq 2$ within 3 km 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The WSM will coordinate appropriate activities on location • Initiate controlled shut-in in an orderly and controlled fashion. • <i>Operations cease until a new plan to continue is developed and approved by the key STAT representatives and DOE</i> 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The WSM will coordinate appropriate activities on location • If event is induced, communicate with potential “offenders”. If possible, learn what actions are being taken. • Proceed with current operations • For an $M \geq 2$ event at depths > 5 km in a cluster suggesting an imaged fault plane: <ul style="list-style-type: none"> ○ Initiate shut-in in an orderly and controlled fashion. ○ <i>Operations cease until a new plan to continue is developed and approved by the key STAT representatives and DOE</i>
<ul style="list-style-type: none"> • $M \geq 3$ within 5 km 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The WSM will coordinate appropriate activities on location 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The WSM will coordinate appropriate activities on location

¹ WSM is the well site manager. This individual is the FORGE designee supervising the field activities.

	<ul style="list-style-type: none"> • Initiate controlled flowback in an orderly and controlled fashion. • <i>Secure the well. When it is established to be safe to do so, POOH, and rig down service company</i> • <i>Operations cease until a new plan to continue is developed and approved by the STAT and DOE</i> 	<ul style="list-style-type: none"> • Initiate controlled flowback in an orderly and controlled fashion. • <i>Secure the well.</i> • <i>Operations cease until a new plan to continue is developed and approved by the STAT and DOE</i>
<ul style="list-style-type: none"> • $M \geq 3$ within 5 to 15 km 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The DSM will coordinate appropriate activities on location • No changes to operations • UUSS Duty Seismologist will issue a press release 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The DSM will coordinate appropriate activities on location • No changes to operations • UUSS Duty Seismologist will issue a press release

*DSM--Drilling Site Manager

Table 2: Actions During Periods of Utah FORGE Non- Stimulation and Circulation

Observations	Actions: UT FORGE Reservoir	Actions: Not UT FORGE Reservoir
<ul style="list-style-type: none"> • No anomalous seismic events 	<ul style="list-style-type: none"> • No actions, Follow good engineering and safety practices 	<ul style="list-style-type: none"> • No actions, Follow good engineering and safety practices
<ul style="list-style-type: none"> • $10 M \geq 1$ in 24 hr within 3 km • Events propagating along an imaged fault plane 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager.
<ul style="list-style-type: none"> • $M \geq 2$ within 3 km • Total loss of drilling mud that cannot be cured in 30 minutes 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. • The WSM will coordinate appropriate activities on location. Ongoing operations at Utah FORGE will cease until a plan to continue is approved by Utah FORGE management, and possible the DOE and key STAT representatives • If the trigger is the result of loss of drilling mud: <ul style="list-style-type: none"> ○ Rig crew and WSM continue to work on curing the losses ○ Drilling may resume with or without returns AFTER consultation with Utah FORGE management, and possible the DOE and key STAT representatives 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. • If event is induced, communicate with potential “offenders”. If possible, learn what actions are being taken. • If Utah FORGE activities are scheduled to begin within 48 hours, follow actions defined for Actions During Utah FORGE Stimulation and Circulation
<ul style="list-style-type: none"> • $M \geq 3$ within 5 km 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. • The WSM will coordinate appropriate activities on location. Ongoing 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. • The WSM will coordinate appropriate activities on location. Ongoing operations

	operations at Utah FORGE will cease until a plan to continue is approved by Utah FORGE management, and possible the DOE and key STAT representatives	at Utah FORGE will cease until a plan to continue is approved by Utah FORGE management, and possible the DOE and key STAT representatives
<ul style="list-style-type: none"> • $M \geq 3$ within 6 to 15 km 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The WSM will coordinate appropriate activities on location • No changes to operations • UUSS Duty Seismologist will issue a press release 	<ul style="list-style-type: none"> • Notify WSM, Operations Superintendent and Project Manager. The WSM will coordinate appropriate activities on location • No changes to operations • UUSS Duty Seismologist will issue a press release

Press Release Template

PRESS RELEASE

University of Utah Seismograph Stations

Released: [DATE] [TIME] MDT

The University of Utah Seismograph Stations (UUSS) reports that a [major/minor] earthquake of magnitude X.X occurred at [TIME] on [DATE]. The epicenter of the shock was located about X mi [DIRECTION] of [CITY/TOWN]. Since 1981, the UUSS has located XX M2 or greater events within 15 mi of this event's epicenter. The largest of these events was a magnitude X.X which occurred on [DATE].

[Extra paragraph, see below]

Anyone who felt the earthquake is encouraged to fill out a survey form on the US Geological Survey website:

[https://earthquake.usgs.gov/earthquakes/eventpage/\[EVID\]/tellus](https://earthquake.usgs.gov/earthquakes/eventpage/[EVID]/tellus)

Extra paragraphs

<5km from FORGE, M<4.5:

This earthquake is X mi from a geothermal energy site and may be related to geothermal energy development. No damage is expected for this magnitude.

<5km from FORGE, M>4.5:

This earthquake is X mi from a geothermal energy site and may be related to geothermal energy development.

6-15km from FORGE, M<4.5:

While there are geothermal energy sites in the area, this earthquake is unlikely to be related as it is X mi away from geothermal energy development activity. No damage is expected for this magnitude.

6-15km from FORGE, M>4.5:

While there are geothermal energy sites in the area, this earthquake is unlikely to be related as it is X mi away from geothermal energy development activity.