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	Attn: Mr. John Ellis		Fort Collins, CO
File:	Disposal Cell	Date:	March 2, 2017

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**Reference: 2016 Seismic Activity in Oklahoma and Disposal Cell Seismic Design**

This memorandum reviews the recent earthquake activity in Oklahoma with respect to potential effects of this activity on the disposal cell at the Sequoyah site (the Site). This memorandum has been prepared for Sequoyah Fuels Corporation (SFC) by Stantec Consulting Services Inc. (Stantec) to address comments by the US Nuclear Regulatory Commission (NRC) on the seismic stability of the disposal cell at the Site.

A probabilistic seismic hazard analysis (PSHA) was performed for the Site in 2005 (LaForge, 2005) and reviewed by NRC. Recent seismic activity (specifically seismic activity induced by oil and gas recovery) has prompted NRC to request a review of the assumptions made in the 2005 PSHA and the resulting ground accelerations used for the disposal cell stability analyses.

**Site Background and Seismicity**

The Site in eastern Oklahoma (near the town of Gore) is east of the primary area of induced seismicity resulting from oil and gas recovery shown on Figure 1 (Petersen et al. 2016). The 2005 PSHA analysis used a minimum event magnitude of 3.0 in order to "...eliminate the possibility of induced earthquakes and the clear bias introduced by the large number of these events..."

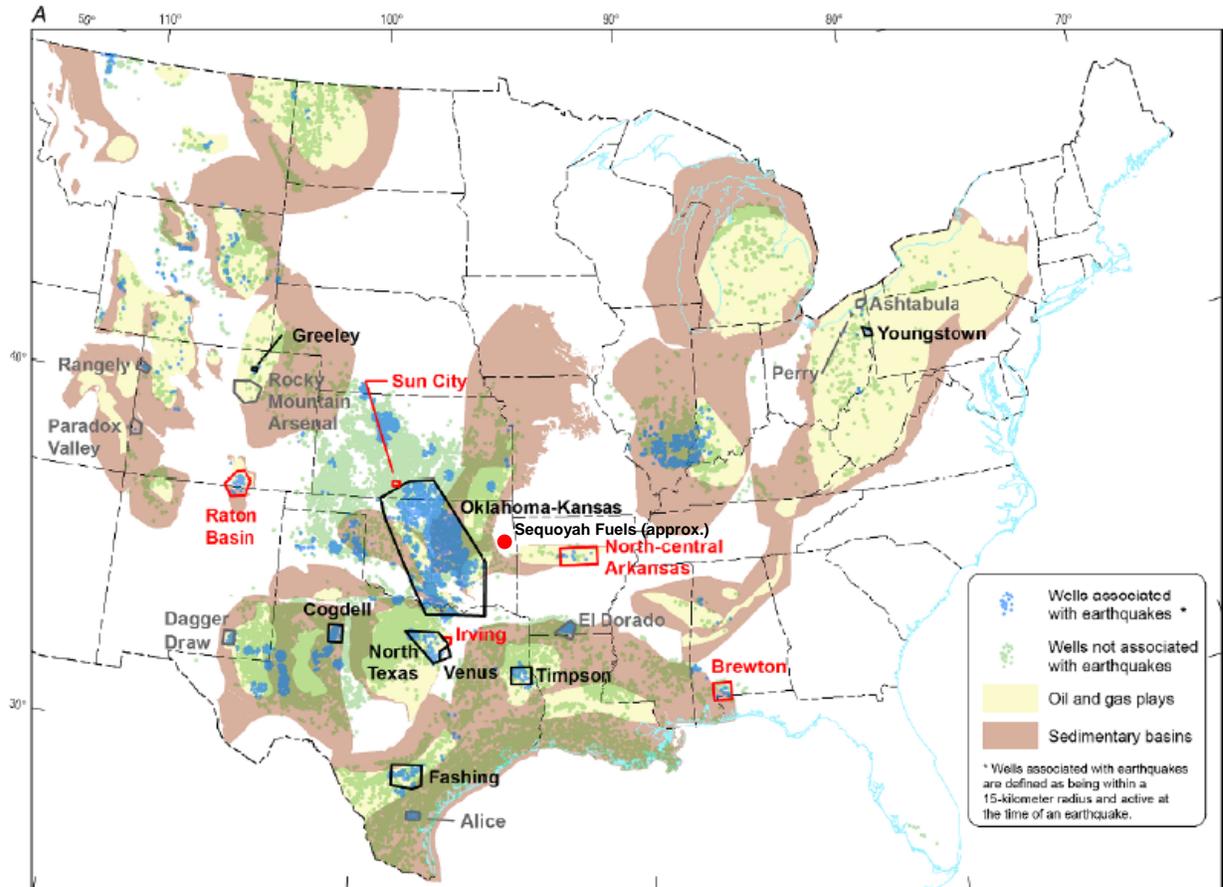
Three earthquakes were recorded in Oklahoma in 2016 with magnitudes greater than 5.0 (Oklahoma Geologic Survey, 2016). One of these was the largest recorded event in state history (magnitude 5.8) on September 3, 2016, centered approximately 122 miles (196 km) northwest of the Site. A magnitude 5.0 earthquake occurred west of Cushing, OK, approximately 102 miles (164 km) northwest of the Site, on November 7, 2016. Two additional events with magnitudes of 5.1 and 4.8 were recorded on February 13, 2016 and January 7, 2016, respectively, approximately 215 miles (346 km) northwest of the Site. The larger magnitude earthquakes (5.0 and greater) were located in the region of extensive oil and gas recovery shown on Figure 1.

Also during 2016, two smaller earthquakes were recorded within 31 miles (50 km) of the Site. The first was magnitude 2.7, located 13 miles (21 km) north of Vian (approximately 14 miles (23 km) northeast of the Site) and the second was magnitude 1.5, located about 6 miles (10 km) west/northwest of Whitefield (approximately 22 miles (35 km) southwest of the Site) (Oklahoma Geological Survey, 2016). Seven earthquakes of magnitude 2.5 or greater, have been recorded within 62 miles (100 km) of the Site (USGS, 2017) since completion of the 2005 PSHA.

The USGS does not currently differentiate between induced earthquakes and natural earthquakes in the Advanced National Seismic System (ANSS) Comprehensive Earthquake Catalog (ComCat). Historical earthquakes with a magnitude of 3.0 or greater were used in the 2005 PSHA with the following magnitudes and distances from the site:

- 23 earthquakes in the 3.0 – 4.0 magnitude range,
- 8 earthquakes in the 4.0 – 5.0 magnitude range: 50 to 125 miles from the site, and
- 2 earthquakes in the 5.0 – 6.0 magnitude range: with magnitudes of 5.0 and 5.5, approximately 115 miles and 150 miles from the site.

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**Figure 1: Map showing locations of oil and gas plays and sedimentary basins in relation to wells that have been associated with induced seismicity (Petersen et al. 2016).**

The closest earthquakes to the Site used in the 2005 PSHA were in the 4.0 – 5.0 magnitude range. The 2005 PSHA used ground motion prediction equations (GMPE) by Toro et al. (1977) and Atkinson and Boore (1995). These equations produced a mean horizontal acceleration of 0.16g for a return period of 10,000 years.

**Resulting Ground Motion**

Figure 2 shows the actual measured peak ground acceleration (PGA) from the USGS ShakeMaps website for the 2016 magnitude 5.8 event. The station closest to the Site (7 km northwest) registered a PGA of 0.006g and the station located approximately the same distance (197 km) from the epicenter as the site, registered a PGA of 0.005g. These measured accelerations are significantly lower than the PGA of 0.16g from the 2005 PSHA. The PGA from the 2005 PSHA was also conservatively increased following NRC review to a PGA of 0.27g for the disposal cell slope stability analyses.

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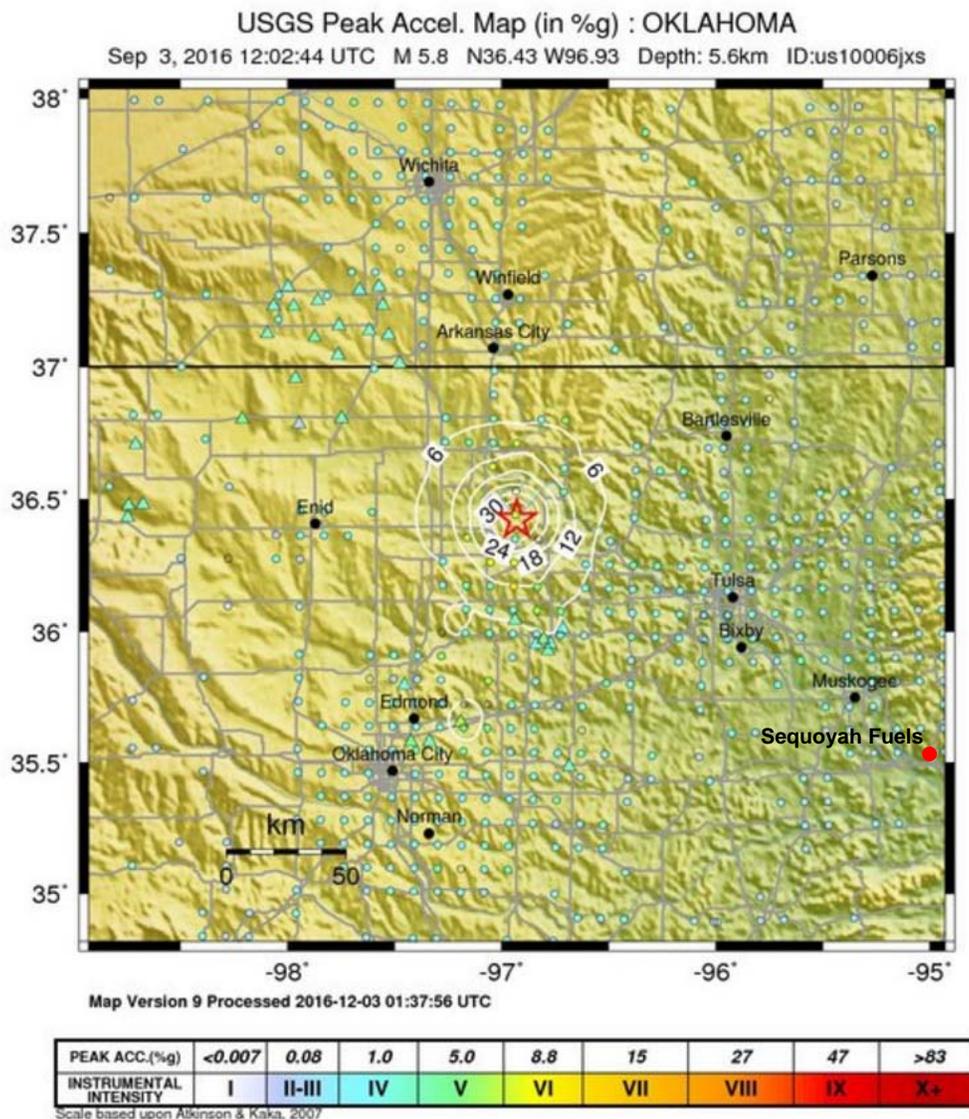


Figure 2: Map of Peak Ground Accelerations for the  $M_w = 5.8$  earthquake on September 3, 2016 (approximate site location shown with red circle).

**Summary**

This review indicates that the GMPEs previously used are still appropriately conservative for use in predicting ground motions at the site, even with the recent induced seismicity in the region. No changes or updates are necessary for the disposal cell seismic stability analyses. Induced seismicity from oil and gas production is inherently difficult to predict since frequencies and earthquake magnitudes are affected by economic and political influences. Although future induced seismicity in the vicinity of the Site cannot be predicted based on

March 2, 2017  
Sequoyah Fuels Corporation  
Page 4 of 5

**Reference: 2016 Seismic Activity in Oklahoma and Disposal Cell Seismic Design**

past activity, the actual measured PGA values from induced seismic events relative to the conservative PGA used in the seismic stability analyses indicates that an appropriate amount of conservatism has been used for a 10,000-year return period.

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## References

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