ATTACHMENT C

TAILINGS CELL LIQUEFACTION ANALYSES

OBJECTIVES:

- Evaluate liquefaction potential during operation and closure and seismic induced settlements of the proposed Tailings Cells at closure.

GIVEN:

- Native soils are not likely to liquefy during the design seismic event (Golder, 2008a).
- Topography for the original ground surface and tailings cells during operation is given in Golder (2008b).
- Closure cover configuration is given in Kleinfelder (2010).
- Tailings densities and consolidation parameters at closure are given in Golder (2010).
- Cover material densities are given in Kleinfelder (2010).
- The Maximum Considered Earthquake (MCE) has a peak seismic acceleration of 0.161 g with a return period of 2,475 years based on a $\mathbf{M_w}$ 4.8 earthquake located 15.5 km from the project (Kleinfelder, 2008).
- The Design Earthquake (DE) (taken as 2/3 of MCE) has a peak ground acceleration of 0.107 g (Kleinfelder, 2008).

ASSUMPTIONS AND METHODOLOGY:

- Use the methodology by Youd et al. (2001) to estimate the cyclic stress ratios (CSR) as

$$CSR = \frac{\tau_{avg}}{\sigma'_{v0}} = 0.65 \frac{a_{\max}}{g} \frac{\sigma_{v0}}{\sigma'_{v0}} r_d$$

where

a_{max} is the maximum ground acceleration, a_{max} =0.107 g (Kleinfelder, 2008);
σ_{v0} is the total vertical stress;
σ'_{v0} is the effective vertical stress; and
r_d is a stress reduction coefficient defined as (Youd et al., 2001):

$$r_d = \frac{1.000 - 0.41163z^{0.5} + 0.04052z + 0.001753z^{1.5}}{1.000 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^2}$$

where

z is depth below ground surface in meters.

- Calculate effective and total stresses by using the geometry and densities from Table 2;
- Water table is assumed to coincide with the tailings surface at closure (Golder, 2008b). Note that this assumption is conservative as it neglects the influence of desiccation and assumes that the drainage at the base of the tailings cell is ineffective.
- For conservatism, the tailings strength was assumed equal to 10% of the vertical effective stress (see e.g. Vick, 1983), i.e., cyclic resistance ratio (CRR) is set to 0.1.
- Determine tailings critical state line (CSL) from the normal consolidation line (NCL) reported by Golder (2010). Use the methodology described by Wood (1990) to obtain NCL and CSL parameters defining the void ratio vs. effective stress relationships:

$e = N - \lambda \ln \sigma'_{v0}$ - NCL
$e = \Gamma - \lambda \ln \sigma'_{v0}$ - CSL

Both, consolidation and critical state parameters are given in Table 1:

Table 1 – Consolidation and Critical State Parameters

λ	κ (Note 1)	Γ (Note 2)	N
0.0955	0.0191	1.1244	1.1774

Note: (1) Swelling index estimated as 20% of λ value.
(2) $\Gamma = N - (\lambda - \kappa)\ln 2$ (see e.g., Wood, 1990).

MATERIAL PROPERTIES:

- The material parameters used in the stability analyses are summarized in Table 2.

Table 2 – Material Properties

Material	Thickness (ft)	Unit Weight (pcf)
Vegetative Cover and Rock Mulch combined	4.0	100.3
Capillary Break	0.5	112.9
Bio - Intrusion Layer	0.5	100.3
Radon Barrier	5.7	112.1
Interim Layer	2.0	100.3
Tailings	Varies	97.7(dry) / 125(bulk) (Note 1)

Note: (1) Tailings densities from Golder (2010)

The dry tailings density of 97.7 pcf, calculated for the end of the deposition cycle (Golder, 2010), was used for liquefaction analyses. For the tailings specific gravity of Gs=2.8 (Golder, 2010), one can determine the average tailings void ratio as:

$$e = \frac{Gs\,\rho_w}{\rho_{dry}} - 1 = \frac{2.8 \times 62.4\,pcf}{97.7\ pcf} - 1 = 0.788\,.$$

From the known tailings void ratio, the bulk tailings density can be determined as

$$\rho = \frac{\rho_w (Gs + e)}{1 + e} = \frac{62.4\,pcf\ (2.8 + 0.788)}{1 + 0.788} \approx 125\ pcf\ .$$

RESULTS:

- Calculated CSR and CRR values shown in Figure 1indicate that the top 50 to 60 feet of tailings material might liquefy in the event
- Figure 1 indicates that the tailings are not likely to liquefy after the closure cover is placed.
- Assuming the tailings height of approximately 70 feet and full liquefaction of tailings during the seismic event, one can calculate the liquefaction induced settlement of approximately 26 inches.
- A complete liquefaction of the underlying tailings would result in a reduction of the cover slope of approximately 1.0%.

CONCLUSIONS

- Liquefaction analyses indicate that the tailings might liquefy in the event that the design earthquake occurs during the Tailings Cell operation.
- Tailings liquefaction is not likely during closure assuming the anticipated seismic loading.
- Even in the unlikely event of tailings liquefaction, the closure cover grades are anticipated to remain positive.
- The above analyses are considered conservative based on the utilized strength parameters and the assumptions made (fully saturated tailings, ineffective drainage system, negligible tailings desiccation, fully developed excess pore pressures during the seismic event).

REFERENCES:

Golder Associates Inc. (Golder). (2008a). Phase 2 Geotechnical Field and Laboratory Test Program, Piñon Ridge Project, Montrose County, Colorado. Prepared for Energy Fuels Resources Corporation. October. Project No. 073-81694.0001.

Golder Associates Inc. (Golder). (2008b). Tailings Cell Design Report, Piñon Ridge Project, Montrose County, Colorado. Prepared for Energy Fuels Resources Corporation. October. Project No. 073-81694.0003.

Golder (2010). "Tailings Cell Foundation and Closure Cover System Settlement Analysis Addendum - Piñon Ridge Project, Montrose County, Colorado" – letter prepared for Energy Fuels Resources Corporation, Golder project No. 073-81694.022.1, April 9, 2010.

Kleinfelder, Inc. (Kleinfelder) (2008). "Design Ground Motions at Piñon Uranium Mill, Colorado." Memorandum to Golder, January 14, 2008.

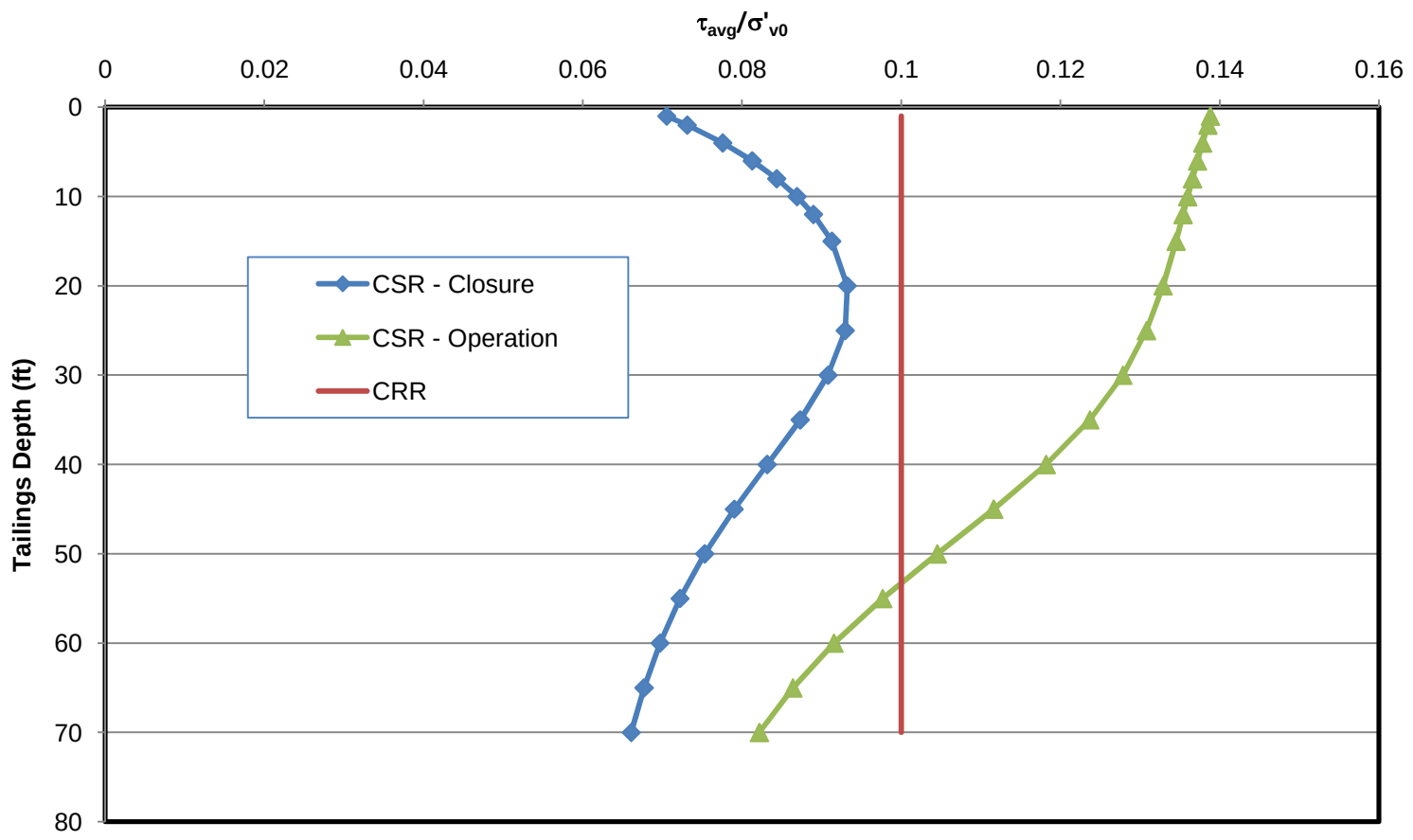
Kleinfelder. (2010). Tailings Cell Closure Design Report, Energy Fuels Corporation, Piñon Ridge Project, Montrose County, Colorado. September 10, 2010.

Vick, S.G. (1983**).** Planning, Design, and Analysis of Tailings Dams, by, John Wiley & Sons , New York, 1983, 369 p., ISBN 0-471-89829-5, reprint was published in 1990 by BiTech Publishers Ltd. , Richmond B.C., Canada (ISBN 0-921095-12-0)

Youd, T.L., I.M. Idriss, R.D. Andrus, I. Arango, G. Castro, J.T. Christian, R. Dobry, W.D. Liam Finn, L. F. Harder Jr., M.E. Hynes, K. Ishihara, J. P. Koester, S. S. C. Liao, W. F. Marcuson III, G. R. Martin, J. K. Mitchell, Y. Moriwaki, M. S. Power, P.K. Robertson, R. B. Seed, K. H. Stokoe II. (2001). Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, *J. Geotechnical and Geoenvironmental Engineering,* Vol. 127, No. 10, ASCE.

Wood, D.M. (1990). "Soil Behaviour and Critical State Soil Mechanics", Cambridge University Press, New York.

FIGURES



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TITLE

TAILINGS LIQUEFACTION POTENTIAL

CLIENT/PROJECT

ENERGY FUELS RESOURCES CORPORATION
PIÑON RIDGE PROJECT - MONTROSE COUNTY, COLORADO

DRAWN	GG	DATE	Nov-10	JOB NO.	073-81694
CHECKED	DLG	SCALE	AS SHOWN	DWG. NO.	
REVIEWED	KFM	FILE NO.		FIGURE NO.	FIGURE 1