Memorandum

To: Steve Tarlton, Colorado Department of Public Health and Environment

cc: Hilary White, Sheep Mountain Alliance
Warren Smith, Colorado Department of Public Health and Environment

From: Dennis O'Leary, Ph.D., USGS retired

Date: 12/15/2010

Subject: Comments on Energy Fuels' proposed Pinon Ridge uranium mill

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The proposed Pinon Ridge uranium mill site in Paradox Valley has serious deficiencies for long-term storage of radioactive mill tailings. Because radioactive mill tailings must be isolated from the accessible environment for at least 1,000 years, optimum confinement should require a geological barrier. However, the site not only lacks a geological barrier to toxic infiltration, in the event of tailings cell liner leakage the site has high potential for groundwater induced subsidence and consequent tailings pond failure. Therefore, the following comments address: 1) effectiveness of tailings confinement for the projected isolation period, 2) consequences of failure of the tailings confinement system. An additional problem is the probability that ground water for mill operations and tailings management will be insufficient over the projected period of mill operation (≥20 years).

Subsurface conditions at the proposed mill site

The mill complex is to be constructed on alluvial sediment. The alluvial sediment over most of the site lies on a jumbled mass of broken shale, gypsum, anhydrite, and clay formed by solution, collapse, and flow of salt of the supporting Paradox Formation. This residuum constitutes a caprock, as much as 300 m thick, on the underlying salt core of the valley. Seismic and drillhole data provided by Kleinfelder Inc. for Energy Fuels, Inc., show that the caprock within the proposed site has about 65 feet of irregular relief which is filled in by the overlying alluvium (Geological Associates, 2007). At its shallowest point the caprock is within 30 feet of ground surface (Geological Associates, 2007).

Groundwater in contact with the top of the salt formation in the vicinity of the proposed mill site is nearly saturated with sodium chloride. Flow of saline groundwater toward the Dolores River from the proposed Pinon Ridge mill site can be inferred from observation of groundwater levels in wells installed in the southeastern and northwestern extremities of the proposed mill site area (Golder Associates, 2008). The elevation of groundwater in exploratory boring EX-15 located 3.6 miles southeast of the proposed mill site is at an elevation of 5,500 feet amsl, whereas the elevation of groundwater in boring EX-14 located 2.3 miles northwest of the site (toward the Dolores River) is at approximately 5,143 feet amsl (see Figure 1.1, Golder Associates, 2008, for boring locations). The difference in these groundwater elevations (i.e., about 350 feet over a distance of 5.9 miles) translates to approximately a one percent (1%) groundwater gradient toward the Dolores River. Bureau of Reclamation studies show that the Dolores River picks up more than 205,000 tons of salt annually as it passes through the Paradox Valley and receives input from the saline groundwater. Brine inflow rates are estimated to range from 0.2 to 2.1 cubic feet per second (Golder Associates, 2010). Because of the net loss of salt and the maintenance of river grade across the valley, there is also a bulk flow of salt toward the axis of the valley and toward the river. Movement of the salt core is slow and variable, but as long as infiltration and stream erosion occur within the valley, and salt is removed by the Dolores River, and deposition by mass movement occurs along the canyon walls, salt uplift will continue and the caprock will continue to deform.

Seismic surveys conducted at the site (Geological Associates, 2007), and subsequent exploration drilling in 2008, by Kleinfelder (2009a) identified at least six buried faults as shown in Figure 7 and illustrated on the geologic cross-sections in Figures 8 and 9 (Kleinfelder, 2009a). Because caprock formation involves net volume loss, most local faults are normal faults (Geological Associates, 2007), which slip in response to bulk subsidence. However, salt movement within the last several hundred thousand years has created an uplift of caprock along the axis of the valley; the southeastern extent of that uplift lies within the proposed mill site boundary (Site Geology Report, fig.4). Satellite images confirm this feature. The southern margin of the uplift is subparallel to the six faults that crosse the tailing ponds site. Because these faults are likely caused by salt uplift, they are considered reverse faults:

• Fault #1 – lying near the foot of Davis Mesa and trending WNW-ESE; upthrown to the north.
• Fault #2 – lying under the footprint of the future mill and trending WNW-ESE; upthrown to the south.
• Fault #3 – lying under the southwest part of Tailing Cell 1A and trending WNW-ESE; upthrown to the north.
• Faults #4, #5, and #6 – closely spaced and lying under Tailing Cells sites B and C, likely en echelon with displacement between 10 and 30 feet up to the north and probably dipping steeply to the south. Faults 4, 5, and 6 form a displacement zone from 500 to 600 feet wide between the salt/caprock mass and more rigid Mesozoic strata to the southeast.

Because the salt deforms by flow, little or no elastic energy is built up within the upper km of the valley floor. Therefore, earthquake hazard and abrupt fault motion is unlikely near the site. However, lack of elastic strain also means that faults and fractures are open and are unsealed down to the supporting salt mass. Such fractures, including the wide fault zone present beneath the site, are fast pathways for infiltration to the deep groundwater. Under present climatic conditions the alluvial surface layer at the site forms a barrier to infiltration to the fractured caprock. But if the alluvium were removed, any water consistently present to the caprock would pass via fracture flow down about 400 feet to the water table and would there dilute the saline water. Kleinfelder (2009b) reports that caprock will likely be penetrated during excavation for tailings ponds, especially ponds B and C; Appendix G, figs. 1, 2). The dilution would enhance local solution of salt and thereby destabilize the overlying caprock. Geological Associates (2007) and Kleinfelder (2009a) reported evidence of solution weathering (i.e. sink holes) near the mill site; the smaller faults in the area probably are also a result of local subsidence caused by subjacent groundwater solution.

Because of the weak salt substrate, fault displacement could occur by creep, which is governed by rate of subjacent salt flow as well as salt solution. Intermittent creep displacement would not easily be recognized in nearly uniform, unconsolidated alluvium, especially if creep rate is comparable with the rate of alluvial deposition. Although solution and subsidence are probably not active or are imperceptible because of low infiltration and slow groundwater movement, it is crucial to consider whether mill construction and activity, especially leaking mill effluent, could reactivate fault movement. The uppermost sediment layer at the proposed site (soil unit 5) is reddish-brown to dark brown, clayey to fine sand (SM/SP), moist, soft, clay and sand, interpreted as an interbedded sheet flow deposit having a maximum thickness of 1.5 feet (Kleinfelder, 2009a). Because Soil Unit 5 overlies the A-Horizon of Soil Unit 4, Soil Unit 5 is believed to be contemporary in age (Kleinfelder, 2009a). Soil unit 5 does indicate that the proposed mill site could be subject to major flooding at any time.

Tailings cell design and long-term performance

Uranium mill tailings typically contain 85% of the original ore radioactivity and almost all heavy metals associated with the ore (Robinson, 2004). Typically also, approximately 5 -10 percent of the original amount of uranium in the ore remains after it has been processed (Diehl 2004). Ra-226, Rn-222, Th-230, Pb-210 and uranium will be present in the tailings (Savignac, 2009). Other hazardous tailings components may include selenium, molybdenum, cadmium, arsenic, and lead (Dwyer, 2008). Potentially hazardous mill reagents remaining in tailings can include salts of chloride, nitrate, ammonia and sulfate as well as organic compounds (Landa, 1980). Adequate and continuous dust suppression during mill operation therefore is a necessity. This means that both an uninterrupted water supply and a saturated (excess water) condition within the cells must be maintained. Energy Fuels, Inc. proposal documents state that within the tailings cells no more than 10 acres may be open (Kleinfelder, 2009b) and available for dusting. Sprinkling of tailings solution or raffinate on the beaches will minimize dust generation, but some tailings solids may dry out on the beaches and become airborne. In fact, unless around the clock “sprinkling” or complete submergence is attained, it is certain that dust will be airborne during part of every year until the ponds are permanently sealed.

Toxic dust suppression should cease to be a problem after the projected end of mill operation, when the tailings cells are to be covered by six different layers that are designed to provide distinct seal/protection features. The function of each layer is described in Kleinfelder (2009b).

Although each of the six cover layers may be “designed” for a particular function, in fact all but one layer will consist of “native soil” excavated from the tailings pond sites. For design purposes this mixed “native soil” is assumed to be silty sand (Kleinfelder, 2009b) but in fact it refers to any combination of the soils and sedimentary lithologies excavated for the tailings cells. This material is chiefly sand and silt with lesser clay or clayey sand. Fine to coarse gravel and cobble-sized materials present in discontinuous layers and lenses in the sediments will be intermixed with the finer-grained excavated sediments. Some of the alluvium is weakly to moderately cemented with calcareous material; the older soil units contain “primary carbonate marker horizons” (stage II to II+ C horizons). At the lower depths of some cell excavations caprock may be included (Kleinfelder, 2009b). Additional classification and compaction testing will be performed on the stockpiled soil prior to cover construction (in other words, none of the stockpiled excavated sediment is known to be suitable for the intended purposes). It is not clear how the mixed, stockpiled “native soil” will provide the discrete and specific functions designated for each of the six layers (except for layer 4). In effect, the tailings cells will be covered with a layer of borrow (except for layer 4), capped by coarse gravel.

The tailings cells are designed to have a conventional two-layer membrane liner underlain by a minimum of three feet of “low permeability soil liner”. The source and composition of the “low permeability soil liner” is not identified; presumably it will be “native soil.” The chosen liner material is 60 mil HDPE “not susceptible to degradation in the presence of tailing solution” (Kleinfelder, 2009b). The components of the tailing cell impoundment structures, liner, and dewatering system are stated to have been designed to satisfy the long-term containment criteria (i.e. 1,000 years). Although the cell design is claimed to provide containment and isolation from the accessible environment for 1,000 years, the cell design is typical for a sanitary landfill or other conventional toxic wastes disposal site. A critical consideration of this system is to maintain minimal hydraulic head on the lower (secondary) composite liner, thereby preventing a driving hydraulic force required for any seepage to occur to the environment. In other words, the primary (HDPE) liner must be leak-proof. Energy Fuels is not confident that isolation is guaranteed even for the life of the proposed mill (≤40 years): tailing cell A is designed for “contingency storage” in case the liner system within one of the sub cells is “not operating properly” and requires inspection and repair (Golder Associates, 2008). It is unclear what kind of repair is envisioned or could be accomplished under operating conditions. Review of HDPE membrane performance indicates that Golder Associates lack of confidence in cell function is justified.

HDPE cell liner performance

Technical information and performance evaluation of HDPE membrane is available online from industrial testing firms, commercial and state environmental and waste containment standards reviews, and from vendors and manufacturers of alternative products. This information may not be peer-reviewed and may represent specific and narrow objectives. The following summary is gathered from such readily available sources. It must be considered indicative of HDPE performance in a tailings cell application, and is not meant as an authoritative statement. Nevertheless, the results point to a need for a much more thorough testing and appraisal of HDPE-based tailings cell design proposed by Energy Fuels, Inc.

HDPE is a widely used product owing to its UV resistance, low cost and very good overall chemical resistance. However, HDPE is prone to environmental stress cracking (ESCR) due to a crystal lattice structure (**http://www.cwneal.com/Article.cfm?articleid=10020**). Since the properties of HDPE, a viscoelastic material, are dependent on time, temperature, and rate of loading, instantaneous test data cannot be expected to reflect material behavior after installation. Therefore, values of the modulus and strength should be obtained under exposure conditions (stress, time, and temperature) that simulate the end-use application (D.V. Reddy and Gregory R. Sitomer Center for Marine Structures and Geotechnique Department of Ocean Engineering, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431).

Exposure of some HDPE materials to low stress levels will lead to slow crack propagation, especially if the crack were initiated by surface cuts or scratches, seam area grinding, or folds in the geomembrane. Slow crack growth may take years to develop, thus making it difficult to predict true service life of HDPE geomembranes (http://www.paneltanks.com/completed%20jobs/Polypropylene%20Tech%20Facts.pdf). HDPE also has a high coefficient of thermal expansion; it undergoes extreme thermal expansion and contraction. This creates installation problems that can result in short term failure of the membrane in tension even where the liner has a cover material

(Data from Seaman Corporation).

The predominant mode of premature HDPE membrane failure is a quasi-brittle fracture initiated at stress concentrating geometries. Installation of HDPE liner therefore must avoid creation of folds and wrinkles. Wrinkles that exist during the placement of the cover will not necessarily flatten; in many cases folds will either be left in a compressed vertical position or in a prolapsed position. In landfills such folds form dams; if a hole exists in the liner the head created by the wrinkle dam will accelerate the volume of leachate passing the liner. In addition, the local bending stress focussed at a fold increases the likelihood of stress crack development (http://www.alltechindustries.com/pdf/All_Tech_Industries_UltraCOAT_vs_HDPE.pdf). Significant loss of strength in geomembrane, from 10% to 70% (Elias, 1990), can occur during installation. The amount of strength loss can depend on gradation, angularity, and maximum size of the backfill particles, weight, type of construction, and compaction equipment (Allen, 1991).

Failure of HDPE due to environmental stress becomes more likely with time because HDPE strength degrades via a series of oxidation reactions that produce free radical polymer chains (alkyl radicals). The chemical degradation of polymer decreases both tensile strength and strain to failure (elongation). The limit of service life of polymeric materials is often selected as a 50% reduction in a specific design property. This is commonly referred to as the halflife time, or simply the "halflife". However, at halflife, the material still can function, albeit at a decreased performance level with a factor-of-safety lower than the initial design value.

Table 2 shows predicted halflife of HDPE membrane under various conditions, as determined by research conducted by the Geosynthetic Research Institute (GRI).

Table 2 - Lifetime prediction of HDPE (nonexposed), in years, at various field temperatures (refs)

In Service Temperature (C°)	Stage "A"(yrs.)		Stage "B"(yrs.)	Stage "C"(yrs.)		TotalLifetime years
	Std OIT	HP-OIT	Field Data	(max.)	(min.)	(ave. values)
20	200	215	30	255	149	449
25	135	144	25	132	77	270
30	95	98	20	70	41	173
35	65	67	15	38	22	111
40	45	47	10	21	12	73

Stage A: Antoxident depletion time; levels of antioxidant depletion for HDPE geomembranes as required in the GRIGM13 Specification (e.g., Sangram and Rowe, 2004). The GRI data for Standard and High Pressure Oxidative Induction Time (Std OIT and HP-OIT) includes measured values from Hsuan and Guan (1997) research via GRI. Stage "B" Induction time to onset of degradation; estimated values from field samples by GRI. Stage "C" time to reach 50% degradation (halflife); values from Gedde, et al. (1994)

Data in Table 2 indicate that the halflife of covered HDPE geomembranes (formulated according to the current GRI-GM13 Specification) is estimated to be 449-years at ambient temperature of 20°. The majority of research on HDPE degradation deals with nonexposed HDPE used in landfill applications. Thermocouple monitoring of a municipal waste landfill liner in Pennsylvania for over 10-years (Koerner and Koerner, 2005) revealed that during the initial 6-years the liner temperature was approximately 20°C; during the subsequent 4-years the temperature increased to approximately 30°C. Under these conditions the halflife of this geomembrane is predicted to be from 270 to 449 years. The site is still being monitored (see Koerner and Koerner, 2005). Whereas covered HDPE promises service lifetime of hundreds of years, the elevated temperatures of exposed or nearly exposed geomembranes in other applications (e.g. uncovered tailings cells in semi-arid environments) can reduce halflife by as much as an order of magnitude.

Leakage through the primary liner of modern HDPE-lined waste disposal facilities is common (**http://www.stopwmx.org/liner.html - Presentation By Dennis E. Williams, Ph.D. president of GEOSCIENCE Support Services, Inc. Before The Board Of Supervisors Of San Bernardino County)**. Bonaparte and Gross (1990) summarized the field data from the leakage detection layers of double-liner systems at 23 double-lined landfills and 7 surface impoundment facilities. The leakages were attributed to top liner failure. Bonaparte and Gross

(1990) concluded that "...properly constructed geomembrane top liners that have undergone CQA (construction quality assurance) cannot consistently limit top liner leakage to a value of less than 5 gpd/acre." Giroud and Bonaparte (1989) discussed several examples of the detection of leaks in double-lined landfills. In one case, the top liner of a landfill exhibited a total leakage rate of 250 gpd [unspecified area] through the geomembrane top liner when the landfill was filled with 6 inches of water. The authors calculated that a 4 mm diameter circular hole could have been the source of this leakage rate.

Groundwater supply

Groundwater investigations by Golder (2008c) showed that in most drillholes across or adjacent to the proposed mill site, groundwater does not occur at depths below the Chinle/Moenkopi contact. Groundwater at the deeper Moenkopi/Hermosa contact was documented at two locations (MW-6 and MW-8B) and is likely the result of groundwater flow through fractures across the Chinle and Moenkopi contact to the top of the Hermosa Formation (Kleinfelder, 2009a). The nine test wells and three "production wells", spaced 1000 feet or less apart, drilled and sampled by Kleinfelder (2009b) have varied water chemistries and different recharge rates; the wells indicate local lithologic heterogeneity and hydrologic barriers within the caprock. Golder Associates (2008) well tests revealed a Chinle/Moenkopi aquifer from 40' to 80' thick. This local aquifer has an estimated 5-year sustained pumping rate ranging from 100 to 175 gallons per minute (Kleinfelder, 2009a; Golder Associates, 2009, p. 31). Although the permeability of the aquifer is high, in the range of 10-3 cm/s, the aquifer's limited thickness may limit higher groundwater production rates (Golder Associates, 2008). Golder Associates (2008) pointed out that the aquifer consists of gravelly lentils and channel fills within the otherwise impermeable red shales: neither of the redbed formations contains contiguous permeable layers that could host and deliver the required quantities of groundwater over the lifetime of the mill (Golder Associates, 2008).

The "production wells" are located in a narrow zone of closely spaced faults along the valley wall (Figures 2.2, 2.3, and 4.1, Golder Associates, 2008). Cross sections C-C' and D-D' (Golder Associates, 2008) indicate that the faulted Mesozoic section, about 400-500 ' thick, rests on Hermosa Formation, presumably caprock. This structural configuration indicates that the production wells have limited capacity to supply the projected water needs. The faults influence aquifer behavior as indicated by measured differences in water levels across the fault traces and measured aquifer responses to hydraulic testing. If the valley wall faults do have hydrologic storage capacity, as Golder Associates (2008) infer, then the groundwater supply will be quickly depleted. When stressed by pumping, the faults and fracture systems will depressurize quickly and draw water from the rock matrix. Thus, in the short term, the aquifer behaves as a fracture controlled system under stress (Golder Associates, 2008).

The southern boundary of the aquifer is not known, but is probably marked by the crest of Davis Mesa (Kleinfelder, 2009a; the "groundwater divide.") The "groundwater divide" (Golder Associates, 2008) provides for a very limited recharge area, most of which lies on steeply eroded and faulted canyon wall. To the northwest, toward the center of Paradox Valley, the aquifer is limited by the Hermosa formation (caprock), based on the drilling results.

The aquifer configuration bounded to the south by the "groundwater divide" and to the north by the valley caprock (salt core) contact forms the basis for Golder Associates' structurally realistic conceptual hydrologic model (Scenario 2, Golder Associates, 2008), which posits an aquifer width of 4,500 feet. In this scenario groundwater delivery could reach 104 gpm, a rate that assumes aquifer recharge of 40 gpm. Sustainable production is estimated at 64 gpm (a pumping rate that will not deplete the aquifer within 5 years).

Energy Fuels, Inc. appreciates the serious deficiency in groundwater supply at the proposed site, as expressed in the following letter excerpt:

> From: letter to Mr. Steve White, Director, Montrose County Land Use Department, dated 11/07/08, in response to 10/28.08 Comment Letter re Special Use Permit, concerning reliable water supply for the mill.
>
> from Frank Filas, Environmental Manager, EF
>
> "Aquifer tests conducted in August (08) and recently completed modeling indicate that the aquifer at the base of the mesa is capable of providing only about half the water supply needed to operate a 1,000 ton per day mill. The most conservative production rate for the aquifer at the base of Davis Mesa is 104 gpm and the highest rate is 175 gpm. the 500 ton per day mill calls for a nominal water supply of 150 gpm. The 100,000 gallons per day (untreated) water offered by Naturita is about equal to 75 gpm and would require 18-20 tanker

truck runs per day for a 500 tpd mill operation. Well water at the site is not potable; it would require either a treatment facility at the mill or purchase and trucking of potable water from an unidentified source.

Water supply evaluation
Pinon Ridge Project
Montrose County, Colorado

Golder Associates
Nov 2008 073-81694.0014

Siting criteria versus site conditions

CDPHE regulations emphasize the need for a stable geological setting to minimize risk of toxic effluent reaching groundwater. The proposed Pinon Ridge mil site does not meet the CDPHE criteria, and the Energy Fuels site development plan does not adhere to the CDPHE regulations nor does it account for the site deficiencies.

Criterion 1A of the CDPHE Licensing Requirements for Uranium and Thorium Processing (6 CCR 1007-1, Part 18) states that "The general goal... in siting and design decisions is **permanent isolation of tailings** and associated contaminants by minimizing disturbance and dispersion by natural forces, and to do so without ongoing maintenance." … site features which ... must be considered in selecting among alternative tailings disposal sites ... include "**natural conditions as they contribute to continued immobilization and isolation of contaminants from ground-water sources."** Therefore, it is critically important to have an accurate and complete understanding of the geologic structure of the proposed mill site and the surrounding valley floor setting. Present data indicate that the proposed mill site does not meet criterion A; tailings pond isolation will depend entirely on an engineered barrier system, the integrity of which cannot be guaranteed beyond the time the mill ceases operation.

Criterion 1B states that **The site selection process must be an optimization to the maximum extent reasonably achievable in terms of the features in Criterion 1A.** Therefore, choice among alternative sites must be based on environmental features that contribute most to long-term stability. Review of alternative sites indicates that the Honeywood site has better containment features that the Pinon Ridge site.

Criterion 1C states: **In the selection of disposal sites, primary emphasis must be given to isolation of tailings or wastes, a matter having long-term impacts, as opposed to consideration only of short-term convenience or benefits, such as minimization of transportation or land acquisition costs. While isolation of tailings will be a function of both site and engineering design, overriding consideration must be given to siting features given the long-term nature of the tailings hazards.** Therefore, geologic and environmental factors must outweigh economic and engineering considerations. This criterion is not met by the proposed mill site or the mill operations plan.

Paragraph 5A(1) states that the tailing pond liner shall be
(b) **Placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift.** Present data do not demonstrate adequate liner support capability or long-term liner integrity over the unstable caprock/salt complex.

Criterion 5G(2) states the importance of understanding the geological structure of the proposed setting: "**...the characteristics of the underlying soil and geologic formations particularly as they will control transport of contaminants and solutions. This includes detailed information concerning extent, thickness, uniformity, shape, and orientation of underlying strata. Hydraulic gradients and conductivities of the various formations must be determined. This information must be gathered from borings and field survey methods taken within the proposed impoundment area and in surrounding areas where contaminants might migrate to ground water. The information gathered on boreholes must include both geological and geophysical logs in sufficient number and degree of sophistication to allow determining significant discontinuities, fractures,**

and channeled deposits of high hydraulic conductivity." The reports and data indicate the key geologic unit at the site is the caprock, a setting of unusually complex structure and deformation history. More detailed surveys are needed to adequately characterize the hazard presented by the caprock. The Kleinfelder reports do not meet this criterion.

Conclusions and recommendations

A uranium mill, such as the proposed Pinon Ridge mill, produces two products: yellowcake and radioactive tailings. The yellowcake may perhaps be profitable for the mill operators over a period of up to 40 years; the tailings remain a public liability for as long as a millenium. Because of the long-term public health hazard and the possibility of widespread environmental contamination, (including in this case release to the Dolores River), CDPHE stipulates strict conditions for uranium mill tailings confinement. Both a geologic barrier and an engineered barrier are required for tailings isolation.

The proposed Pinon Ridge mill plan fails to meet CDPHE standards for toxic tailings confinement on two counts: 1. the proposed mill site in Paradox Valley does not provide a geological barrier for tailings confinement, 2. the tailings pond/cell design is a conventional design for sanitary landfills and for toxic chemical waste (including non radioactive mill tailings). As such, there is little confidence that the proposed isolation system could outlast the 40 year projected mill operation let alone a period more than twenty times as long. Research on HDPE confinement systems indicates an optimal functional life for the tailings cells of about 500 years; under the described mill site conditions I would estimate between 40 to 100 years before leaks are detected.

Three potential hazards are presented by the proposed Pinon Ridge site: 1. differential bedrock subsidence sufficient to break the tailings pond seals, 2. flow of effluent in fault/crush zones directly to the water table sufficient to accelerate subsidence, 3. transport of radioactive tailings components downgradient toward the Dolores River. Golder Associates (2010) estimated that groundwater from the Project site will take over 300 years to reach the Dolores River. This estimate assumes porous-type flow to the river, which in turn assumes a homogeneous porous aquifer. This is an unbounded estimate; Golder Associates (2010) also noted that groundwater flow toward the Dolores River could be faster "in some areas" due to localized fracture-type flow. Fracture flow probably controls flow velocity within the upper 500 m of the caprock/salt core complex. Because of the uncertainty of contaminated flow reaching the Dolores River, and the significance of this irreversible degradation, Energy Fuels should perform an exacting modelling and data analysis of downgradient flow from the site to the Dolores River.

A leaking tailings cell will deliver effluent containing radionuclides to the caprock. The caprock contains little soluble matter, and groundwater is very deep. However faults and fractures beneath the tailings ponds, especially the large fault zone, provide a fracture pathway for effluent. The effluent will change the water chemistry at depth (dilute it and consequently increase salt dissolution), which will result in strain on the overlying caprock. Long-term subsidence would put strain on the containment membrane and exacerbate leakage. It would be very difficult to create a stable, flat foundation for the cells in the caprock because of the close deformation, varied structure and different rock compositions.

Given the level of toxicity and the requirement for long-term confinement, could the Pinon Ridge site be found acceptable? To determine this, the planning deficiencies must be overcome. A probabilistic hazards analysis of the site and the plan should be conducted by Energy Fuels, calling on impartial experts in tailings isolation, HDPE performance, groundwater, salt tectonics and geochemistry, rock mechanics, Pleistocene geology, soils science, and radioactive waste disposal. This analysis should be done to quantify the levels of risk and uncertainty of tailings pond failure and radioactive materials dispersal, and the environmental/health consequences. At present, the only statements on these topics are assertions by Energy Fuels that no dangers exist. Second, a much more detailed and critical database on the site should be obtained to support the application and the plan. The reports provided, primarily by Kleinfelder, Inc., are perfunctory and are based on no apparent sample design. Some of the reports seem not to have been adequately reviewed: one report states the mill will require 144 gpm water (Golder Associates, 2009); another cites 300 gpm. one report states that uranium at $40/lb will provide a break-even price at $70/lb. Another report states that the mill will concentrate U234, not U235. The distribution and hydrologic isolation of the fault blocks at the site is not adequately conveyed by the Kleinfelder interpretations. For example, the shallow seismic report, its data and interpretations (figs. 4, 6, Geological Associates, 2007) are not compatible with the hydrologic cross sections C-C' and D-D' (figure 5) in the site geology report (Kleinfelder, 2009a). These discrepancies indicate that the plan is not well thought out and that accurate information is not yet available. No attempt has been made to attain a reasonable level of quality assurance.

Given the liklihood that the 500-600-foot wide fault zone at the proposed site represents a fast pathway for groundwater infiltration to the salt horizon, at least two exploratory core holes should be drilled in this zone. Presently there are no data on this structure (see Appendix G, Site Geology, fig. 1, Kleinfelder, 2009a). Given what is known about the performance properties of HDPE membrane, and given the exposure and working of the tailings cells (e.g. annual exposure, temperature excursions, freeze-thaw conditions, wet-dry alternations, bulldozer or other equipment and activity on the liners, creep and settling phenomena), Energy Fuels needs to provide credible tailings cell failure scenarios, risk/hazard assessment, and the repair procedures they will have available. This level of preparedness is especially appropriate in the planning in light of the complete lack of any preparation for the BP Gulf oil spill.

A serious drawback to the proposed Pinon Ridge mill site is deficient groundwater supply. The Golder Associates reports describe a limited and uncertain aquifer available for projected mill production. Interruptions of water supply because of transportation or other issues might be tolerable for mill performance, but failure to maintain safe conditions at the open tailings cells on that account should not be tolerated.

Given the inadequate technical database, lack of a suitable geologic barrier at the site, lack of sufficient groundwater for projected operations and for uninterrupted tailings dust suppression, and the possibility of flooding across the site, I recommend that Energy Fuels reconsider CDPHE criterion 5A (2) and perform a thorough investigation of an alternative site. The site that seems most likely to be suitable is the Honeywood site:

> "The Honeywood Site is located on a plateau immediately southeast of Naturita in Montrose County, Colorado (Sections 27, 28, and 34, Township 46 North, Range 15 West and Sections 3, 4, 5, and 9, Township 45 North, Range 15 West). The main access to the site is from SH 141 just east of its intersection with SH 145 and an unnamed county road approximately 3 to 4 miles east of Naturita. This 1,200-acre site includes a reclaimed surface coal mine and approximately 112 acres have been backfilled, graded to approximate original contours, and topsoiled. The site is surrounded by a mixture of private and BLM-administered land parcels of various sizes. The local landfill is located about 1 mile southeast of the Honeywood Site. Shallow groundwater is present over the entire site; however, it would be necessary to gain surface water rights from the San Miguel River basin or groundwater rights from deeper formations to meet the daily fresh water requirements for mill operations. The site is underlain by low permeability bentonitic shales that would provide additional protection of groundwater resources from the construction and operation of the tailings disposal facilities. Broad Canyon Landfill, southeast of the mill site, was permitted without a synthetic liner due to the existence of this shale layer. The property is currently in an active state of reclamation. This site was eliminated due to its proximity to Naturita, transfer of regulatory responsibility (and bond release) of the site from the Colorado Division of Reclamation, Mining and Safety (DRMS) to the CDPHE, and because it would be necessary to drill and blast to place tailings cells below ground level."

Given the enthusiasm for the proposed mill by residents of Naturita and the promise of jobs to these residents from Energy Fuels, the proximity of the Honeywood site to Naturita is certainly an economic asset, and, according Energy Fuels, Inc., should not be a safety concern. (It is unclear why proximity to Naturita is considered a detriment by Energy Fuels, Inc.; proximity should be considered an asset.) Geologically, this site is superior to the Pinon Ridge site, and it offers a more reliable source of groundwater. Transfer of regulatory responsibility and bond release from DRMS to CDPHE is hardly a problem considering the general enthusiasm for this project at the state and county level. The cost of drilling and blasting to place tailings cells below ground level is trivial with respect to gain of a long-term geologic barrier for radioactive tailings confinement and the long-term cost of failed tailing cells in Paradox Valley.

References

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Qualifications of author

Dennis O'Leary, PhD, is a geologist retired from 39 years of service with the U.S. Geological Survey. His areas of specialty include structural geology, tectonics, geomorphology, and Pleistocene geology. Dr. O'Leary worked for 17 years on the Yucca Mountain Project to evaluate the site for the nations's first high-level nuclear waste repository. This work included site characterization and evaluation and formulation of tectonic models, and probabilistic seismic and volcanic hazards analysis. He worked for two years on the USGS Toxic Substances Hydrology Program at the Amargosa Desert, NV, research site. During the 1970s Dr. O'Leary conducted a structural survey of the Paradox Basin, including Paradox Valley, in cooperation with DOE, to evaluate the salt deposits for a national high-level nuclear waste repository candidate site. Dr O'Leary's most recent publication is *Tectonic models for Yucca Mountain , Nevada*, in: The Geology and Climatology of Yucca Mountain and Vicinity, Southern Nevada and California, 2007, Stuckless, J.S, and Levich, R.A., eds., Geological Society of America Memoir 199, p. 105-154. Dr. O'Leary holds a PhD in geology from Pennsylvania State University, an MS in economic geology and ore beneficiation from Missouri School of Mines, Rolla, and an BS in geology from Boston College.