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Subject: **Evaluation of the *Draft Methane Recovery Plan* and the *Revised Final Extraction Test Report* (Source: G.N. Richardson & Associates, Inc., July, 2000). Work Assignment R1A00008**

G.N. Richardson & Associates, Inc. (GNRA) on behalf of Lexington County performed efforts to remedy the off-site migration of landfill gas (LFG) at the Lexington County 321 Landfill. The summary of these efforts is in the following two documents: *Draft Methane Recovery Plan* and the *Revised Final Extraction Test Report* (Source: G.N. Richardson & Associates, Inc., July, 2000). Lockheed Martin REAC reviewed the above documents; the following considerations and recommendations are based on this review.

The current effort by GNRA is reasonable. However, to verify that this approach is appropriate and to assist in an effective design, we need to understand the conditions of the landfill and environs that generated the off-site migration of LFG.

Considerations for LFG Transport, Collection, and Treatment

LFG Transport Mechanisms. The nature of the specific transport mechanism depends on the type of waste (i.e., solid or liquid) exposed to the atmosphere. Several physical mechanisms describe the behavior of volatile compounds as they may migrate through a landfill and be released into the atmosphere. Transport may occur by three principal mechanisms:

- molecular diffusion
- convection
- molecular effusion

Molecular Diffusion. Molecular diffusion occurs in gas systems when a concentration difference exists between two different locations within the gas. Diffusive flow of gas is in the direction in which its concentration decreases. The concentration of a volatile constituent in LFG will almost always be higher than that of the surrounding atmosphere, so the constituent will tend to migrate to a lower concentration area (the ambient air).

medium concentrations.

Convection. Convective flow occurs where a pressure gradient exists between the landfill and the atmosphere; gas will flow from higher pressure to lower pressure regions. Where it occurs, convective flow of gas will overwhelm the other release mechanisms in its ability to transport and ultimately release materials into the atmosphere. The rate of gas movement is generally orders of magnitude faster for convection than for diffusion. Although convective and diffusive flow may be in opposing directions and result in an overall tendency toward cancellation; however for most cases of LFG gas recovery, diffusive and convective flows occur in the same direction.

Molecular Effusion. When waste material has been compacted but not yet covered, effusion occurs when diffused gas releases from the top of the landfill. This is not an issue at the Lexington County 321 Landfill.

Therefore LFG migration depends on its driving forces, concentration and pressure gradients. To measure these gradients, we can observe the methane concentration and LFG volumetric flow rate. The product of the two measurments gives us the mass flow rate (concentration x volume flow = mass flow). The mass of methane reaching a location from a source with the potential of exceeding its Lower Explosive Limit depends on the volumetric flow rate from that source and the concentration of that flow. Therefore to provide a preliminary evaluation of the fundamentals of gas movement at Lexington County 321 Landfill, the certain data in the *Draft Methane Recovery Plan* and the *Revised Final Extraction Test Report* was evaluated.

To explore the affect of methane concentration at the landfill, the values of the Methane Average Percent in Table 1 of the *Draft Methane Recovery Plan* were plotted on Figure 1. The relative concentration of methane was categorized as low (0 to 19.9%)m, medium (20 to 39.9%), high (40 to 49.9%) and very high (50+%). It should be noted that not all wells listed in Table 1 were found on Figure 1.

Wells near the Blanchard and Drake properties had low and medium concentrations of methane. Between the Blanchard Property and the landfill in the north northwest corner of the landfill, nine wells (BL-1, BL-2, BL-3, GV-17, GV-18, GV-19, GV-20, GV-21, and SM-14) have average percent of methane below 20%. Between the Drake Property and the landfill in the west northwest corner, one well, B-2, had less than 20% methane, while five wells (B-1, B-3, DP-1, and DP-2, and DP-3) had concentrations between 20 and 39.9% methane. Furthermore in the northern half on the landfill cap, the area closest to the Blanchard and Drake properties, one well had low and five had medium concentrations of methane.

On the other hand, concentrations of methane were highest in the central and southern portion of the landfill, areas furthest from the Blanchard and Drake properties. Five wells (C-19, C-20, C-21, C-22, and C-25) in the center of the landfill cap had very high concentrations (50+%) of methane; five wells (C-7, C-16, C-23, C-24, and C-26) had high concentrations; and one well (C-18) had medium values. In the southern portion of the landfill (C-8 to C-16), six contained very high concentrations, three contained medium concentrations.

To determine LFG convection at the landfill, the values of the Flowrate Average CFM in Table 1 of the *Draft Methane Recovery Plan* were similarly plotted on Figure 1. The relative flowrate of LFG was categorized as low (0 to 4.9 CFM), medium (5 to 9.9 CFM), high (10 to 14.9 CFM) and very high (15+ CFM).

As with methane concentration values, overall values of methane flowrates were generally lowest for wells near the Blanchard and Drake properties. Between the Blanchard Property and the landfill, wells BL-1, BL-2, GV-18, GV-21, and SM-14 have average flowrates of methane below 5 CFM; well GV-19 has a medium flowrate; and wells GV-17 and GV-20 were high. Of the five wells between the Drake Property and the landfill, only well DP-3 had an average flowrate between 5 and 9.9 CFM, the rest were below 5 CFM. Additionally for the six wells in the northern half on the landfill cap, two had low, three were medium, and one was high.

Flowrates of methane were highest in the central and southern portion of the landfill, areas furthest from the Blanchard and Drake properties. In the center of the landfill cap, well C-22 showed a very high flowrate; C-20 and C-25 were high; the remaining were medium. In the southern portion of the landfill, C-10 and C-12 showed very high flowrates; C-8 had high; the remainder in this area were low or medium.

In summary, the areas north northwest and west northwest beyond the landfill cap and the northern portion of the cap were found to have lower methane concentrations and flowrates, and hence lower mass LFG than the central and southern portions of the cap. Therefore if significant methane concentrations were detected in the ambient air near the Blanchard and Drake properties, there may be a possibility of fugitive methane in other areas of the landfill.

Factors Affecting LFG Transport Mechanisms. LFG transport mechanisms are affected by the following factors:

- permeability or intrinsic permeability
- depth of groundwater
- conditions within the waste
- man-made features including landfill liner and cap systems

Permeability. The LFG permeability is a function of both its intrinsic and relative permeabilities. The permeability distribution has a profound influence on gas flow rates and gas recovery rates. Coarse-grain refuses typically exhibit large values of gas permeability and more uniform gas flow patterns. Both of these factors tend to promote increased LFG recovery rates. By contrast, fine-grained refuses are characterized by small values of gas permeability and gas flow patterns, which are primarily restricted to macropores or secondary permeability zone such as fractures.

Borehole logs list the subsurface soil conditions as primarily silty sand. These soil conditions usually have a permeability that does not inhibit gas migration. The capability of these soils to transport LFG off site should be ascertained. If no such historical data is available, air permeability tests need to be performed on site soil.

Subsurface moisture also affects the permeability, and hence LFG migration, and should be addressed when information about permeability is obtained. No data was found about subsurface moisture.

Depth of Groundwater. The water table surface tends to act as a no-flow boundary for gas flow within the unsaturated zone. As a result, it is generally used to estimate the thickness of the zone from which a gas can be moved. The depth to groundwater as well as seasonal variations need to be evaluated during the pre-design process to evaluate well construction requirements as well as the potential for water table upwelling (i.e., the upward rise of the water table toward a vacuum well screened in the unsaturated zone).

Groundwater depths and moisture conditions are not listed. The groundwater conditions beneath and around the landfill may be unknown. If no such historical data is available, groundwater conditions need to be obtained for the site.

Conditions Within the Waste. The distribution and occurrence of waste and debris within the unsaturated zone greatly affects gas migration and recovery rates. The conditions within the waste matrix that may affect soil gas transport include:

- heterogeneities
- porosity
- moisture content

1. Heterogeneities. Heterogeneities are caused by spatial variations in solid matrix type, layering, unusual refuse composition and moisture content. Due to the heterogeneous nature of the landfill environment, there will be some acid-phase anaerobic decomposition and some aerobic decomposition occurring simultaneously in any large-scale landfill, along with the methanogenic decomposition. During the operation of an off-gas collection system, these variations may influence LFG quality, gas flow patterns, and ultimately gas recovery rates within the landfill.

2. Porosity. The landfill waste's porosity (n) is a ratio of the void volume to the total volume of the porous medium, usually expressed as a decimal fraction or percent. These pores can be occupied by gas, water, and/or bacteria.

3. Moisture Content. The moisture content of the solid matrix influences the magnitude of the air phase permeability. Water competes with air to occupy pore space within the solid matrix and ultimately reduces the ability of vapors to migrate through the landfill due to a reduction in the air pathway. This reduction may decrease gas recovery rates.

As evidenced by the GNRA borings, the highly decomposed condition of the landfill waste indicates that moisture and air are entering the landfill and composting the landfill waste. The high methane and carbon dioxide concentration from the extracted LFG analytical tests indicate that the waste decomposition is active, and appears to be in a third phase gas generation due to the roughly balanced methane/carbon dioxide concentrations and the descriptions of the landfill waste obtained from the borings. Anaerobic and aerobic conditions may co-exist in the landfill. However, additional data is needed about the waste's heterogeneities, porosity, and moisture content. If no such archival data exists, this data should be obtained.

Man-Made Features. In some instances, underground utilities such as storm and sanitary sewers or the backfill material associated with these features may produce short-circuiting of air-flow associated with an off-gas collection system. As a result, air-flow may be concentrated along these features rather than within the zone requiring collection. In addition, these features may also provide migration pathways for both free-phase liquids and vapors within the unsaturated zone. As a result, the orientation and geometry of these features may dictate the direction in which the liquids or vapors migrate.

Man-made features need to be examined and evaluated at the landfill to ascertain their role in the off-site migration of LFG.

Site Geology and Stratigraphy. Although boring logs were presented, geologic cross sections and/or fence diagrams have not been presented. An understanding of the subsurface hydrostratigraphy is essential for evaluating LFG migration and planning collection and treatment systems.

No site conceptual model was found in the above reports. It is important to develop a reliable model from existing, archival, and, possibly, additional information so that the landfill can be understood from a 3-D perspective.

LFG Migration Monitoring. Fugitive LFG concentrations at the landfill perimeter at other locations was discussed briefly in the reports: "At this time, LFG has been detected on both the Blanchard Machinery property and the Drake property...currently, the Blanchard and Drake properties are the only adjacent properties affected by methane migration." The assumption is that the concentrations are significantly lower at locations, although this assumption may be due to the fact that there are few humans smelling LFG at other locations along the perimeter of the landfill. The report also states, "During the first year of operation, all portions of the system (as well as methane points currently monitored) will be monitored on a bi-weekly basis." However, it is unclear what methane points are currently being monitored. Therefore, additional monitoring for LFG migration should be performed at the site's perimeter.

Figure 1 shows numerous monitoring devices: wells, probes, vents, and piezometers. Although these monitoring devices exist at the landfill, no information was presented concerning their use, construction or resulting monitoring data. Archival data of LFG at these locations should be obtained and evaluated. If archival data does not exist, additional data should be obtained on gas migration. However before obtaining additional data from the existing monitoring devises noted above, the construction of these devises should be obtained and evaluated before developing a monitoring program. If the existing devises are found suitable, then a monitoring program that uses the existing monitoring devises should be developed and executed.

Gas migration should be monitored both laterally and vertically. Any monitoring event(s) should take into account: spacing for probes, probe depth, and sampling frequency.

Lateral migration monitoring is achieved by installing permanent gas monitoring probes at the periphery of the landfill to check for potential subsurface landfill gas migration and ensure that gas is not escaping beyond the landfill boundary. Vertical migration is monitored across the surface of the landfill by moving portable instruments across the landfill. Locations where instruments measure concentrations above background should be noted and investigated further to check for vertical migration and out-gassing.

Comparison of Various Gas Collection Systems. No historical information was presented concerning the landfill conditions prior to the identification of the methane problem. Is or was a passive methane venting system in place? What type of design and operating conditions? If a passive vent system is in place, is it correctly designed and installed?

The efficiency of a passive collection system depends on good containment of the LFG to prevent direct emission to the ambient air. Generally, passive collection systems have lower collection efficiencies than active systems, since they rely on natural pressure or concentration gradients to drive gas flow rather than a stronger, mechanically-induced pressure gradient. A well—designed passive system, however, can be nearly equivalent in collection efficiency to an active system if the landfill design includes synthetic liners in the landfill liner and cover. Since passive systems rely on venting, in the event that the vent is blocked by moisture or frost, the gas seeks other escape routes including moving into surrounding formations.

Passive systems are not considered reliable enough to provide an exclusive means of protection. With their concentrated vent gas, passive systems may be considered as an uncontrolled air emissions point source by regulatory agencies. In addition, passive venting systems raise the potential for nuisance odor problems because there is no positive system for odor management.

Recommendations

- Gather and evaluate all available archival data (e.g., subsurface geology, methane monitoring information, monitoring devise construction).
- Develop a site conceptual model (if data available).

- Identify data gaps.
- Obtain additional appropriate data.
- Refine site conceptual model (if needed), based on, but not limited to:
    - Additional borings, wells, monitoring points, etc.
    - Collection and evaluation of *in situ* permeability data (e.g., air flow).
    - Quantitative assessment of LFG transport and migration.
- Design optimal collection, treatment, and monitoring system.

The vacuum tests demonstrated that the zone of influence of an active gas recovery system would be quite limited due to the high gas transmissivity properties of the soil.