Countywide Recycling & Disposal Facility
Division of Republic Waste Services of Ohio
3619 Gracemont Street S.W.
East Sparta, Ohio 44626
Phone: 330-874-3855
Fax: 330-874-2426

May 11, 2007

Ohio Environmental Protection Agency, Central Office
Division of Solid and Infectious Waste Management
Attn: Mr. Ed Gortner
PO Box 1049
Columbus, Ohio 43216-1049

RE: SUBMITTAL OF ENGINEERED COMPONENT EVALUATION STUDY, ORDER 3
DIRECTOR'S FINAL FINDINGS AND ORDERS OF MARCH 28, 2007
COUNTYWIDE RECYCLING AND DISPOSAL FACILITY

Dear Mr. Gortner:

Countywide Recycling and Disposal Facility (Countywide) hereby submits the Engineered Component Evaluation Study (ECES) per Order 3 of the Findings and Orders (Orders) dated March 28, 2007. This Plan was prepared by our consultant, Earth Tech, Inc. We have attached an Executive Summary of the report for your convenience.

Countywide considers this submittal as compliance with Order No. 3 and we await your review and approval. As required by Order 3, we have recommended further study, and will use the resources of the Geosynthetics Research Institute and Dr. Robert M. Koerner, Ph. D. to accomplish that study. We would like to meet with your team and experts to discuss the next phase of evaluations at your earliest convenience. If you have questions, please do not hesitate to contact me at (330) 874-3855.

Countywide Recycling & Disposal Facility

Tim Vandersall, P.E.
General Manager

cc/ec: Bill Skowronski, OEPA-NEDO
Kirk Norris, SCHD
Dan Aleman, CHD
ec: Gina Gerbasi, OEPA-CO
Jeff Martin, OEPA-CO
Todd Hamilton, CWRDF
Jason Perdion, B&H
Jim Walsh, SCS Engineers
Mike Michels, Cornerstone
Mike Beaudoin, Earth Tech

cc = printed copy ec = email pdf copy

Countywide Recycling and Disposal Facility

Executive Summary – Engineered Component Evaluation Study

On March 28, 2007, the Ohio Environmental Protection Agency (OEPA) issued Director's Final Findings and Orders (F&O's) which require Countywide Recycling and Disposal Facility (Countywide) to perform tasks aimed at reducing odors and extinguishing a reaction occurring in the landfill. The reaction generates gas, with odor and temperatures above those typically seen in landfills.

Order 3 of the F&O's requires that Countywide perform an evaluation to determine if heat in the area affected by the reaction (Cells 1-6) has damaged the engineered components. The study is called the Engineered Component Evaluation Study (ECES) and consists of two parts as required by Order 3:

- Present a summary of efforts performed to-date regarding integrity of the engineered components
- Describe further measures proposed to evaluate the engineered components, and a schedule for those evaluations.

Summary of Efforts to Date

The entire Countywide disposal area is underlain by a composite liner system which consists of a 60-mil high density polyethylene (HDPE) liner above an engineered- and/or recompacted-clay layer. A highly permeable leachate collection layer lies on top of the HDPE liner. A network of plastic pipes runs throughout the permeable leachate collection layer to facilitate liquid collection.

In February, Countywide performed a water-jet cleaning program of leachate collection pipes. The February cleaning was performed on pipes which lie under and near the area of the reaction. This pipe cleaning program determined that the pipes were clear and open.

In May 2007, Countywide completed measurements of leachate and gas temperatures in the leachate collection system. This ECES provides detail of the temperature measurement program. Further work is recommended to verify the readings; however, the measured temperatures are below those that would compromise the containment capability of the HDPE liner component of the composite liner system.

Further Measures Proposed

Countywide finds no evidence of compromise to the composite liner system or leachate collection system. Nevertheless, Countywide proposes further study to determine whether the observed temperatures (if sustained) could have an effect on the HDPE liner.

Therefore, Countywide proposes to perform additional leachate collection system temperature monitoring. In addition, we propose to utilize the resources of the Geosynthetic Research Institute, and Dr. Robert M. Koerner, Ph. D. as an expert, to evaluate the potential, if any, of the observed temperatures on the natural "aging" process of the HDPE liner component of the composite liner system. Countywide proposes to meet with the OEPA at their earliest convenience, and work closely with their experts to develop a program of further study.

Engineered Component Evaluation Study (ECES) for Countywide Landfill

East Sparta, Ohio

Prepared to Address Order 3
Director's Final Findings & Orders
Effective March 28, 2007

Submitted May 11, 2007

Prepared By:
Earth Tech, Inc.
36133 Schoolcraft Rd.
Livonia, MI 48150

Engineered Component Evaluation Study

Countywide Recycling and Disposal Facility

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1.0 Introduction

Countywide Recycling and Disposal Facility (Countywide) is a Subtitle D municipal solid waste landfill located in Stark County, Ohio, that is owned and operated by Republic Services of Ohio II, LLC. Countywide is permitted and licensed to accept solid waste as it is defined in Ohio Revised Code. Countywide has been in operation since 1991.

In December 2005, Countywide observed that temperatures were beginning to increase in some of the landfill gas collection wells at the facility. Around March to June, 2006, Countywide observed an increase in gas temperatures, accompanied by an increase in emissions noted as gas odors, and other symptoms, which suggested that changes were occurring within the landfill. Further evaluation revealed that the temperatures and increased gas production were caused by an exothermic reaction involving aluminum dross within the central portion of the landfill.

A description of the reaction and efforts made to assess and remediate the situation at the landfill are described in a report entitled "Gas System Operating Review at the Countywide Landfill," dated August 31, 2006, prepared by Cornerstone Environmental Group, LLC (Cornerstone). This report was submitted to the Ohio Environmental Protection Agency (OEPA). The report identified regions within the Cells 1-6 area in the original 88-acre portion of the landfill where the reaction appears to be occurring and the landfill temperatures have increased.

From June 2006 to present, many measures, including the installation of many new gas wells and several new flare stations, have been implemented at the site to increase gas collection, reduce odors, and further assess and determine the extent of the reaction.

On March 28, 2007, the OEPA issued a set of Final Findings and Orders (F&O's), which required that Countywide conduct an "Engineered Component Evaluation Study" (ECES). The requirements of the order, and the associated sections of this report that address the Order requirement are:

"Not later than 45 days after the effective date of these Orders, Respondent shall submit to Ohio EPA for review and comment an Engineered Component Evaluation Study ("ECES"), which shall:

A. *Contain a summary of efforts performed to date to evaluate whether the engineered components in cells 1, 2, 3, 4A, 5A, 5B, 5C, 5D, and 6A have been damaged;* **[See Section 2.0 of this report]**

B. *Contain all data and investigative reports generated to date concerning whether the engineered components in cells 1, 2, 3, 4A, 5A, 5B, 5C, 5D, and 6A have been damaged;* **[See Section 2.0 of this report]**

C. *Detail all measures, methods and techniques Respondent intends to take and rely on to further evaluate whether any of the engineered components in cells 1, 2, 3, 4A, 5A, 5B, 5C, 5D, and 6A have been damaged;* **[See Section 3.0 of this report]** *and*

D. *Recommend a schedule for all measures, methods and techniques Respondent intends to take and rely on to further evaluate whether any of the engineered components in cells 1, 2, 3, 4A, 5A, 5B, 5C, 5D, and 6A have been damaged.* **[See Section 3.0 of this report]**

Ohio EPA may review the ECES in accordance with the procedures set forth in Section VI, Review of Submittals. Upon approval of the ECES by Ohio EPA, Respondent shall implement the ECES in accordance with the schedule contained therein."

This ECES provides a summary of our evaluations to date, and includes recommendations for further evaluation. The summary provided in Section 2.0 includes a description of the existing liner system components, a description of the field work performed at the site and an outline of the results. The recommendations included in Section 3.0 outline the additional field work required at the site and the proposed studies moving forward to further address the observed temperatures at the site.

2.0 Summary of Evaluation to Date

Section 3745-27-08(B) of the Ohio Revised Code refers to many items as "engineered components" for a sanitary landfill facility. In broad categories, these include:

- In-situ foundation
- Composite liner system
- Leachate collection and management system
- Surface water control structures
- Composite cap system
- Explosive gas control system
- Access roads
- Groundwater control structures
- Structural fill
- Added geologic material
- Liner cushion layer, and
- Leachate storage tanks

Surface features, such as the stormwater structures or access roads, are affected by settlement, but can be readily maintained. At this point, Countywide has not installed a composite cap system over the 88 acre impacted area; therefore an evaluation of the temperature effects on the cap components is not required. Foundation and structural fill soils installed during the construction of Cells 1 through 6 should not be impacted before the liner systems installed in the cells. Some components of the gas collection system have been affected by large settlements that are occurring, but there is no evidence of heat damage to the gas collection system. Therefore, the focus of this report will be the leachate collection system and the liner systems installed in Cells 1 through 6.

2.1 Description of Leachate Collection System and Liner System

Countywide is one of the few landfills in the state that is entirely underlain by a state-of-the-art liner and leachate collection system (LCS). The landfill was constructed in stages, called "cells." Limits of cells and the layout of the leachate collection system is provided on Figure 1.

In the period between 1991 and 1996, Countywide constructed cells with a composite liner system consisting of compacted clay overlain by a high density polyethylene (HDPE) geomembrane as shown on Figure 2. Starting in 1997, Countywide used the composite liner system shown on Figure 3. Additional detail on the leachate collection systems and liner systems.

<u>Leachate Collection Systems</u>
The leachate collection systems constructed at Countywide have two main components for the conveyance of leachate above the liner system: a protective cover layer consisting of granular high-permeability drainage material placed over the liner system on the entire cell floor and a network of perforated pipes contained in the protective cover layer that are surrounded by an extremely-high permeability stone gravel material. Figures 2 and 3 show the leachate collection systems constructed above the liner systems in the existing cells at Countywide.

The particular protective cover layers used at Countywide are as follows:

- Cell 1 – 12 inches of "washed" sand
- Cells 2, 3, 4, 6A, and 5D – 12 inches of No. 8 or No. 9 stone gravel (pea gravel)
- Cells 5A, 5B, 5C – 18 inches of Secondary Tire Chips

The protective cover drainage material serves a two-fold purpose which includes protecting the liner system during construction and initial waste filling operations, and conveying leachate off the liner system through a network of leachate collection pipes to a low point in the cell called a leachate collection sump. The leachate collection pipes and sump locations are clearly indicated on Figure 1. The perforated leachate collection pipes in the cells at Countywide consist of Schedule 80 polyvinyl chloride (PVC) in Cells 1, 2, 3, 5A, 5B, 5C and 5D; and SDR 11 high density polyethylene (HDPE) in Cells 4 and 6A. A horizontal submersible leachate pump is inserted into a large diameter (18" or 24") HDPE perforated pipe that lies at the bottom of a sump at the low point in each cell. Leachate is extracted from the cell by the pump which is designed with instrumentation to turn on when leachate accumulates in the sump.

<u>Liner Systems</u>

The liner systems constructed in the cells at Countywide are "composite" liner systems. Figures 2 and 3 show the design cross sections of the two different composite liner systems constructed in the cells at Countywide. These composite liner systems are comprised of a synthetic 60-mil thick high density polyethylene (HDPE) geomembrane placed over a 5-foot thick compacted clay layer or a combined geocomposite clay liner (GCL) and 3-foot thick clay layer. The 60-mil HDPE geomembrane is protected by a nonwoven geotextile fabric, the protective cover granular drainage material, and by five feet of select waste material (which is free of large or sharp objects and industrial wastes).

A composite liner system employs redundancy with the geomembrane and clay layer components to maximize environmental protection. The redundancy of the system is enhanced by the fact that the components of the liner system are made from dissimilar materials. This redundancy allows for maximum environmental protection even if one of the materials is affected by adverse conditions that could occur during construction or operation of the landfill.

2.2 Evaluation of Leachate Collection System Integrity

As shown on the figures in Section 2.2.1, the leachate collection pipes are made of PVC or HDPE material. Figure 1 indicates the type, size, and thickness of pipes used in the different cells. It is known that PVC and HDPE lose strength properties at elevated temperatures (each losing about 35% of their elastic modulus as the temperature to which they are subjected goes from 73° F and 140° F). Since the pipes are under the stress of the overlying waste, these pipes would collapse well before temperatures at the pipes are elevated to a temperature at which essentially all loss of strength occurs (approximated by the "forming" temperature of the materials--about 195° F for PVC and 250° F for HDPE – see Appendix A). This has not occurred at Countywide.

Countywide has performed three field studies which have confirmed that the leachate collection system has not been compromised and is functional as intended. These studies are presented in the following sections.

2.2.1 Leachate Collection Pipe Cleaning

Annually, in the summer, Countywide cleans the network of leachate collection pipes at the landfill. The contractor, Dynamerican, Inc. uses a conventional water-jet sewer cleaner to advance up each 6-inch diameter leachate collection pipe to remove accumulated sediment and determine if the pipes are still open. Each annual event has determined that all pipes were open and functional as summarized on Table 1. The results of these annual cleaning events are submitted to the OEPA in the annual reports from Countywide.

In February 2007, Earth Tech, Inc. provided oversight of an additional leachate collection pipe cleaning, in advance of the annual event. This cleaning was done to determine whether the pipes were still open and functional throughout their length given the presence of elevated temperatures within the landfill since mid-2006.

Seven leachate collection pipes were selected for investigation on February 12, 2007. The locations were selected to traverse portions of the landfill that have exhibited the highest gas well temperatures and gas well drill cutting temperatures. Dynamerican cleaned all seven of the locations throughout their entire length or to the maximum reach of the water jet (850 feet, less the distance that the truck was parked from the pipe opening). On February 16, 2007, Dynamerican returned to clean pipes 5A/B, 5B/C, and 3D. For this event, their equipment had a maximum reach of water jet of 1200 feet.

Results of the February 2007 cleaning are compiled with the previous annual events on Table 1. Figure 4 shows the locations and results of the February 2007 cleaning. No objects or obstructions were encountered, and the pipes were clean to lengths consistent with previous annual events. Therefore, this pipe cleaning event demonstrated that the leachate collection pipes evaluated during the investigation were open and functional through the lengths that were cleaned.

2.2.2 February 2007 Thermocouple Study

Countywide performed a study on February 19 and 20, 2007 to measure the temperatures in the leachate collection pipes using a thermocouple. Temperature measurements were made in select leachate collection pipes within the Cells 1-6 area. A thermocouple was inserted into the leachate collection pipes through the leachate cleanout pipes by attaching it to a pipe camera, and pushing it in the collection pipe for the entire length of the camera cable (300 feet) or until friction along the cell floor would not permit the camera cable to be pushed any further, whichever came first. Temperature was observed during advancement, and then the thermocouple/camera body was withdrawn and moved to the next location.

The thermocouple used for this program was a Mineral Insulated Style AF Metal Transition Single Element, as manufactured by Watlow. The thermocouple is Type K and has a standard Type K temperature range of -328° F to +2500° F, and has an accuracy of + or – 0.05% of the reading plus 0.5° F. Two untwisted wires lead from the thermocouple to the clips at the top of the leachate collection pipe. The clips are connected to a Fluke 51 single-input thermometer for obtaining temperature measurements.

Thermocouples work by sending a weak electrical signal. Consultation with the manufacturer of the thermocouples (Watlow) suggest that long leads of uninsulated, untwisted wire may be resulting in interference due to magnetic fields that could result from areas of high iron or metal in the landfill. Therefore, further work will be proposed to see if the maximum temperature (as well as any other temperatures) can be verified. The manufacturer recommends using "T" type thermocouples and insulated twisted wire to minimize the potential for electromagnetic disturbance. Countywide proposes that this be done in Section 3.

Results of this February 2007study are presented on Table 2 and Figure 5. As shown in Table 2, the temperatures on the side slopes were lower than those on the cell floors. Temperatures on the cell floors ranged from 77.0-134.6° F (the maximum observed temperature of 134.6° F in Line 1D may be affected by a gas condensate knockout feature which delivers warm condensate to this area).

2.2.3 May 2007 Thermocouple Study

As discussed above, the February 2007 thermocouple study was limited by the length of the camera cable and by insufficient stiffness of the camera cable, which did not allow pushing far along the cell floor (working upgrade). Therefore another study was performed in Cells 1-6 in May 2007 to obtain temperatures under the central, bottom portion of the landfill. It was also desired to leave the thermocouple at certain locations so that temperatures could be observed over time.

By May 2, 2007, Countywide had completed installation of dedicated thermocouples into the seven leachate collection sumps (to facilitate leachate temperature measurements required by Order 4.A.5) as well as six locations into selected leachate collection pipes. The initial results of the May 2007 study prepared for this initial report are contained on Table 3.

Thermocouples (the same model as described in Section 2.2.2) were threaded on to the end of a one-inch diameter PVC pipe and pushed down the leachate collection pipes to the desired distance; Figure 7 presents a schematic of the thermocouple installations and the locations in which they were installed. For the long thermocouples, temperature observations were made as the thermocouples were advanced so that installations could be located at a point where maximum temperatures along the length could be recorded.

The first round of temperature measurements on all six of the leachate collection line thermocouples and all seven of the permanent leachate sump thermocouples was performed on May 2, 2007. The results are shown on Figure 6 and summarized in Table 3.

Temperatures on the bottom of the landfill were measured between 77.1°-123.6° F, with the exception of a maximum temperature of 181.5° F which was observed in leachate collection pipe 3B, a PVC pipe. The location of the Pipe 3B thermocouple is near the location of the maximum observed wellhead and downhole temperature observations (see Figure 8). At this location in the landfill, it is likely that the thermocouple is measuring a gas temperature (rather than leachate); it is likely that a layer of leachate under the gas in this pipe may have a lower temperature.

As previously discussed, consultation with the manufacturer of the thermocouples (Watlow) suggest that long leads of uninsulated, untwisted wire may be resulting in interference due to magnetic fields that could result from areas of high iron or metal in the landfill. Therefore, further work will be proposed to see if the maximum temperature (as well as any other temperatures) can be verified. The manufacturer recommends using "T" type thermocouples and insulated twisted wire to minimize the potential for electromagnetic disturbance. Countywide proposes that this be done in Section 3.

2.2.4 Discussion of Tire Chip Drainage Layers

As previously mentioned, Cells 5A, 5B, and 5C employ an 18-inch thick layer of tire chips to serve as the protective cover. The maximum measured temperature in the cells with tire chips was 111.8° F. In November 2006, a cap repair was performed near the top of the leachate collection riser for Cell 5A/B. During that work, the top edge of the tire chip drainage layer was exposed without any observation of fumes or smoke. Therefore, we conclude that there is no smoldering fire or any type of reaction occurring in the tire chip layer.

2.2.5 Performance of Leachate Collection System

As the field studies demonstrate, there is currently no evidence of collapse of the leachate collection pipes, or reduced functionality of the leachate collection system at Countywide. The leachate collection system is functioning well when considering the investigation and cleaning program performed for this report and the continuous flow monitoring that is performed at the site.

The reaction occurring in the landfill has increased the leachate flow volume generated by several times the amount that would be expected. The leachate collection system has performed well by allowing removal of leachate from the landfill during this period of higher leachate generation.

Therefore, we can conclude based on our current field investigations, that there is no evidence of compromise to its physical components or performance.

2.3 Evaluation of Liner System Integrity

Countywide is one of the few landfills in the state that is entirely underlain by a state-of-the-art composite liner and leachate collection system (LCS). Two different composite liners systems have been used at the landfill as shown on Figure 1 and 2. As explained above, these composite liner systems are comprised of a synthetic 60-mil thick high density polyethylene (HDPE) geomembrane placed over a 5-foot thick compacted clay layer or a combined geocomposite clay liner (GCL) and 3–foot thick clay layer.

The integrity of the liner system (its capability to contain leachate within the landfill) is provided by the multiple, redundant layers from which the liner system is constructed. Discussion of liner system integrity is presented in the following sections.

2.3.1 Actual Temperatures on the Liner System

We have assumed that many temperatures measurements in the leachate collection pipes can be used to approximate the temperatures on the liner. As described in Section 2.2, the temperatures are highest in the leachate collection pipes along the floor of the landfill. A "typical" temperature in the leachate collection pipes at Countywide ranges from 100° to 120° F with a maximum observed temperature of 181.5° F under Cell 3 in leachate pipe 3B.

We would expect that the HDPE liner component is likely cooler than the temperatures observed in the overlying leachate collection pipes because:

- there is, typically, another three inches of gravel separation between the bottom of the pipe and the liner surface
- a thin layer of liquid (leachate) is often present on the surface of the liners, and
- the HDPE liner is in direct contact with the clay which has a lower temperature and will cool the HDPE liner (the underlying natural ground temperatures at some depth beneath the landfill is at a year-round 55° F as measured during groundwater sampling).

The May 2007 reading in Cell 3, Line 3B is potentially anomalous and is inconsistent with readings in areas which were similar in terms of location in the landfill. Additional temperature monitoring from the permanent thermocouples installed in May 2007 should provide further data to reconcile the anomaly experienced in the data from the initial studies. In addition, as discussed in Section 2.2.3, we recommend using a different type of thermocouple and lead wire setup in Line 3B to reduce the possibility of anomalous readings by minimizing the potential for electromagnetic flux interference.

2.3.2 Evaluation of Immediate Effects on HDPE Liner

HDPE, as with any plastic material, tends to soften at elevated temperature. Three critical points are often defined as:

- "Softening" temperature, 221° F. This is the temperature at which HDPE softens as defined by ASTM D1525 (the temperature at which a 1 mm^2 flat needle penetrates 1 mm into plastic when loaded with 1,420 pounds per square inch).

- "Forming" temperature, 250° F. This is the temperature at which HDPE becomes pliable for the purpose of deforming it, for example to slip-line a pipe (see Appendix A, Fig. 4).

- "Melting" temperature, 273° F. This is the temperature at which HDPE becomes liquid (see Appendix A, Fig. 4).

Since the maximum temperature on the HDPE liner surface is considered to be less than 181.5° F, we do not anticipate that the current conditions are allowing deformations which could have an immediate adverse effect on the HDPE liner.

2.3.3 Evaluation of "Aging" on HDPE Liner

HDPE is the state-of-the-art geomembrane component due to its superior resistance to chemical attack and its extremely low permeability. It is known that the material can "age", resulting in a reduction in certain physical properties such as. tensile strength, stress/strain modulus, puncture strength, etc.. These physical properties are important during fabrication and installation, and to handle construction loading and the stresses imposed by initial filling. It should be noted that, with the exception of a potentially-extraneous reading of 181.5° F., all of the temperatures observed so far (77 deg. F to 134.6 deg. F) are near ranges seen in other "wet" landfills (around 50 deg. C or 122 deg. F,).

The Geosynthetic Research Institute (GRI) has addressed this issue in a paper titled "Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions" which is included in Appendix B. This paper describes the process of aging of HDPE liner material to the half-life (50% reduction) of its physical properties, especially at higher temperatures. The paper describes the first stage of the aging process as attributable to "oxidation." The laboratory tests which were performed to model the aging process were conducted in an aerobic environment (air was present at the bottom of the laboratory sample). The assumption of air at the bottom of the landfill was made in the GRI paper assuming the liner system was a double HDPE liner system that has a secondary collection zone that could contain oxygen at the bottom of the landfill. The absence of oxygen is known to retard the aging process.

With a composite liner system, conditions at the bottom of the Countywide landfill are anticipated to be nearly anaerobic since the leachate and water contained in the recompacted clay are expected to have low oxygen available. This would be typical for composite liner systems that do not have secondary collection zones that can convey oxygen to the bottom of the landfill. In Section 3.0 we recommend that further study be performed to quantify the availability of oxygen and evaluate other potential oxidation mechanisms that may exist due to the chemistry that exists at the base of the landfill. An assessment would then be made regarding the aging of HDPE liner with elevated temperatures in a depleted oxygen environment.

In addition, it is important to recognize that the half-life predictions contained in the cited paper assume that the geomembrane is subjected to the particular temperatures for the entire lifetime. We know that the conditions of elevated temperatures will not be sustained indefinitely. The "Fire Suppression Plan" which is being prepared to address the requirements of OEPA Order 8, will address the issue of the lifetime of the reaction and associated elevated temperatures.

We recommend that, based on the current design of the composite liner system at Countywide, and the investigations that are summarized herein it appears that additional study on the potential effect of elevated temperatures in a depleted oxygen environment.

2.3.4 Evaluation of Compacted Clay and Geosynthetic Clay (GCL) Liners

As described in Section 2.3, the HDPE liner component is directly underlain by five feet of compacted clay layer, or by a GCL in combination with three feet of the compacted clay layer. When compacted clay is placed, it is in a nearly saturated state at optimum moisture content. In an unprotected state, if saturated clay is exposed to elevated temperatures, moisture can be evaporated out of the clay and can lead to cracking.

The clay liner at Countywide is sandwiched between an HDPE geomembrane liner and a compact underlying structural fill and/or a relatively impermeable natural shale formation. Although it is possible that moisture can be driven out of a GCL or compacted clay liner, with moisture migrating downward, away from the synthetic component, we believe that the conditions at Countywide present a relatively low-permeability base which would inhibit moisture migration. In addition, the large vertical stresses imposed by the waste on the liner system would tend to prevent cracking even if a loss of moisture in the clay occurs.

3.0 Recommended Further Evaluation and Schedule

While there is no evidence that any compromise of the leachate collection or liner engineered systems has occurred, we believe that it would be prudent to continue additional studies to supplement this interim report and prepare a final report for OEPA. The following measures and evaluations are recommended to be instituted by Countywide:

Measure or Evaluation	Schedule
1. Add measurement of LCS (long) thermocouples to the weekly leachate temp. monitoring	Monthly, starting June 1, 2007
2. Perform additional LCS thermocouples monitoring at areas of elevated wellhead temperatures	Start June 1, 2007
3. Conduct another leachate cleanout study on all LCS pipes	By June 15, 2007
4. More completely characterize the conditions at the base of the landfill and further evaluate the HDPE liner with respect to aging	See discussion below
5. Verify, using another style thermocouple, the validity of the potentially extraneous 181.5 degree F reading in Line 3B.	By June 1, 2007

Item 4 would utilize the resources of the Geosynthetic Research Institute, and Dr. Robert M. Koerner, Ph. D. as an expert, to evaluate the potential for long-term impact on the composite liner system. Countywide proposes to meet with the OEPA at their earliest convenience, and work closely with their experts to develop a program of further study. We suggest that the Work Plan could be submitted within 30 days of the approval of this ECES. The Work Plan would propose a schedule for the additional studies and propose revised frequency or discontinuation of Items 1 and 2. The Work Plan would consider the results of the "Fire Suppression Plan" (which is to be submitted May 25) and integrate any results and recommendations contained therein.

TABLE 1

SUMMARY OF DYNAMERICAN'S CLEANOUTS 2001-2007

LENGTH OF WATER JET ADVANCEMENT(1)

COUNTYWIDE LANDFILL
ENGINEERED COMPONENT EVALUATION STUDY

Pipe ID	Length	2001	2002	2004	2005	2006	Feb. 2007[2]	Pipe Material
1A	578	530	530	460	460	450		SCH80 PVC
1B	619	630	630	600	600	600		SCH80 PVC
1C	635	630	630	480	480	450		SCH80 PVC
1D	660	660	660	300	400	450		SCH80 PVC
1E	382	400	400	350	400	400		SCH80 PVC
2A	713	720	720	400	600	600		SCH80 PVC
2B	747	750	750	650	700	700		SCH80 PVC
2C	759	750	750	625	700	700	750	SCH80 PVC
2D	724	630	630	620	650	650		SCH80 PVC
2E	512	510	510	510	500	500		SCH80 PVC
3A	846	850	850	650	650	30[4]		SDR17 PVC
3B	589	610	610	610	550	550	560	SDR17 PVC
3C	859	800	800	560	800	800	800	SDR17 PVC
3D	705	750	750	700	700	720	720	SDR17 PVC
4A	842	850	850	850	850	900		SDR11 HDPE
4B	822	900	900	900	900	900		SDR11 HDPE
4C	987	1000	1000	1000	1000	1000	825[3]	SDR11 HDPE
4D	1171	1175	1175	1100	1100	1100		SDR11 HDPE
4E	1000	970	970	800	800	850	850[3]	SDR11 HDPE
5A/B	1217	1100	1100	1100	1200	1200	1170	SCH80 PVC
5C/D	1143	1100	1100	1100	1200	1200	1125	SCH80 PVC
6A	801	400	400	400	400	400		SDR11 HDPE
6B	878	600	600	600	700	700	825[3]	SDR11 HDPE

Notes:

1) Dynamerican often estimates the length cleaned to the nearest 50 feet
2) This was a limited cleanout event, targeting areas where reaction was believed to be occurring.
3) Equipment used for these cleanout events was limited by 850 feet of hose.
   When truck was parked 25 feet from pipe entrance, the maximum reach was 825 feet.
4) This cleanout damaged during capping of South Slope temporary cap in May 2006.

TABLE 2

TEMPERATURES FROM FEBRUARY 2007 THERMOCOUPLE STUDY

COUNTYWIDE LANDFILL
ENGINEERED COMPONENT EVALUATION STUDY

Riser Number	Date	Dist. Into Riser (ft.)	Temp. (Deg. C)	Temp (Deg. F)
3D	2/19/2007	20	-5	23
	2/19/2007	50	0	32
	2/19/2007	100	10	50
	2/19/2007	111	13	55.4
	2/19/2007	125	32	89.6
	2/19/2007	150	41	105.8
	2/19/2007	169	41	105.8
3B	2/19/2007	0	-7	19.4
	2/19/2007	21	-7	19.4
	2/19/2007	50	-5	23
	2/19/2007	101	0	32
	2/19/2007	130	3	37.4
	2/19/2007	150	42	107.6
	2/19/2007	175	53	127.4
	2/19/2007	181	47	116.6
4E	2/19/2007	0	-3	26.6
	2/19/2007	20	-3	26.6
	2/19/2007	50	-1	30.2
	2/19/2007	100	8	46.4
	2/19/2007	132	13	55.4
	2/19/2007	165	18	64.4
	2/19/2007	184	38	100.4
	2/19/2007	210	41	105.8
	2/19/2007	221	45	113
4C	2/19/2007	0	0	32
	2/19/2007	21	1	33.8
	2/19/2007	52	0	32
	2/19/2007	100	2	35.6
	2/19/2007	130	5	41
	2/19/2007	159	10	50
	2/19/2007	189	37	98.6
	2/19/2007	200	43	109.4
	2/19/2007	211	43	109.4
5A/B	2/19/2007	0	-1	30.2
	2/19/2007	19	0	32
	2/19/2007	51	6	42.8
	2/19/2007	100	20	68

Riser Number	Date	Dist. Into Riser (ft.)	Temp. (Deg. C)	Temp (Deg. F)
5A/B	2/19/2007	133	28	82.4
	2/19/2007	169	33	91.4
	2/19/2007	185	46	114.8
	2/19/2007	200	47	116.6
	2/19/2007	231	46	114.8
	2/19/2007	264	45	113
	2/19/2007	301	44	111.2
2 South	2/20/2007	0	3	37.4
	2/20/2007	25	4	39.2
	2/20/2007	50	6	42.8
	2/20/2007	75	25	77
	2/20/2007	100	27	80.6
	2/20/2007	125	28	82.4
	2/20/2007	150	29	84.2
	2/20/2007	155	29	84.2
5C/D	2/20/2007	0	6	42.8
	2/20/2007	25	10	50
	2/20/2007	50	17	62.6
	2/20/2007	75	22	71.6
	2/20/2007	100	27	80.6
	2/20/2007	125	39	102.2
	2/20/2007	150	40	104
	2/20/2007	175	31	87.8
	2/20/2007	200	29	84.2
	2/20/2007	225	46	114.8
	2/20/2007	250	48	118.4
	2/20/2007	275	43	109.4
Cell 1	2/20/2007	0	6	42.8
CO#1	2/20/2007	12	25	77
Line 1 E	2/20/2007	25	38	100.4
	2/20/2007	51	55	131
Cell 1	2/20/2007	0	6	42.8
CO#2	2/20/2007	14	28	82.4
Line 1 D	2/20/2007	50	34	93.2
	2/20/2007	75	52	125.6
	2/20/2007	100	55	131
	2/20/2007	127	57	134.6

Note: The thermocouple was attached to a pipe camera which was mounted on a heavy cable. Distance that the camera/thermocouple could be pushed into the pipe was limited by the lack of stiffness of the camera cable.

TABLE 3
TEMPERATURES FROM MAY 2007 THERMOCOUPLE STUDY

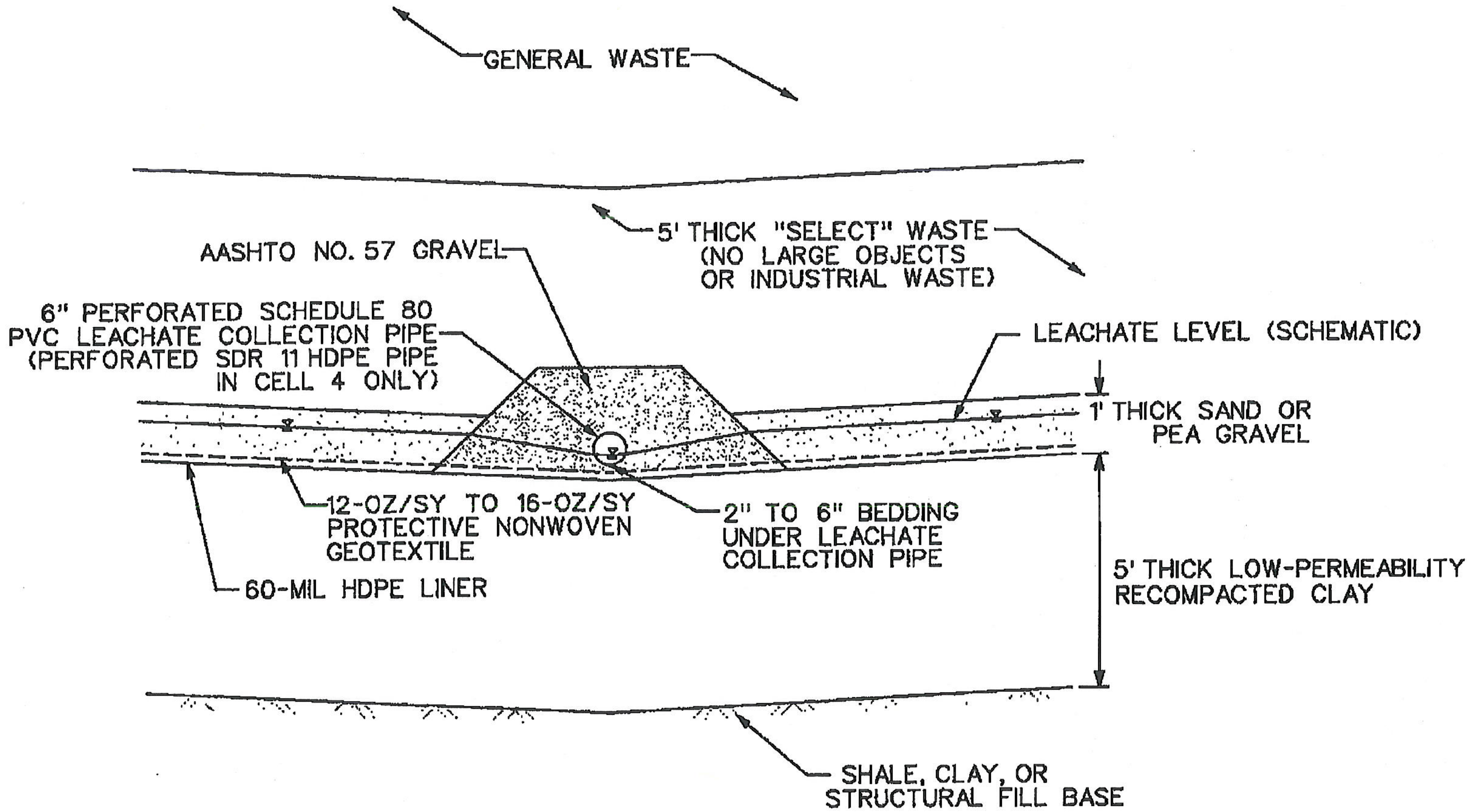
COUNTYWIDE LANDFILL
ENGINEERED COMPONENT EVALUATION STUDY

Leachate Temperature Readings on May 2, 2007

Leachate Sumps	
Cell	**Sump Temperature (F)**
1	98.5
2 N	60.3
2 S	77.1
3	123.6
4	107.2
5 A/B	111.8
5 C/D	105.8

Leachate Cell Pipe Thermocouples		
Cleanout	**Temperature (F)**	**Length (ft)**
1 D	92.2	350
2 C	108.9	740
3 B	181.5	600
4 C	98.7	850
5 A/B	101.7	900
6 B	107.5	810

Note: Reading are to be confirmed using type T thermocouple with insulated shielded twisted wire to reduce potential for electromagnetic flux interference.



NOTE: EACH CELL HAS SLIGHTLY DIFFERENT CONSTRUCTION DETAILS. THE FEATURES SHOWN HERE ARE COMMON TO EACH

EarthTech
A tyco International Ltd. Company

MAY 2007

FIGURE 2
TYPICAL LINER SYSTEM
CELLS 1-4

COUNTYWIDE LANDFILL
ENGINEERED COMPONENTS
EVALUATION STUDY

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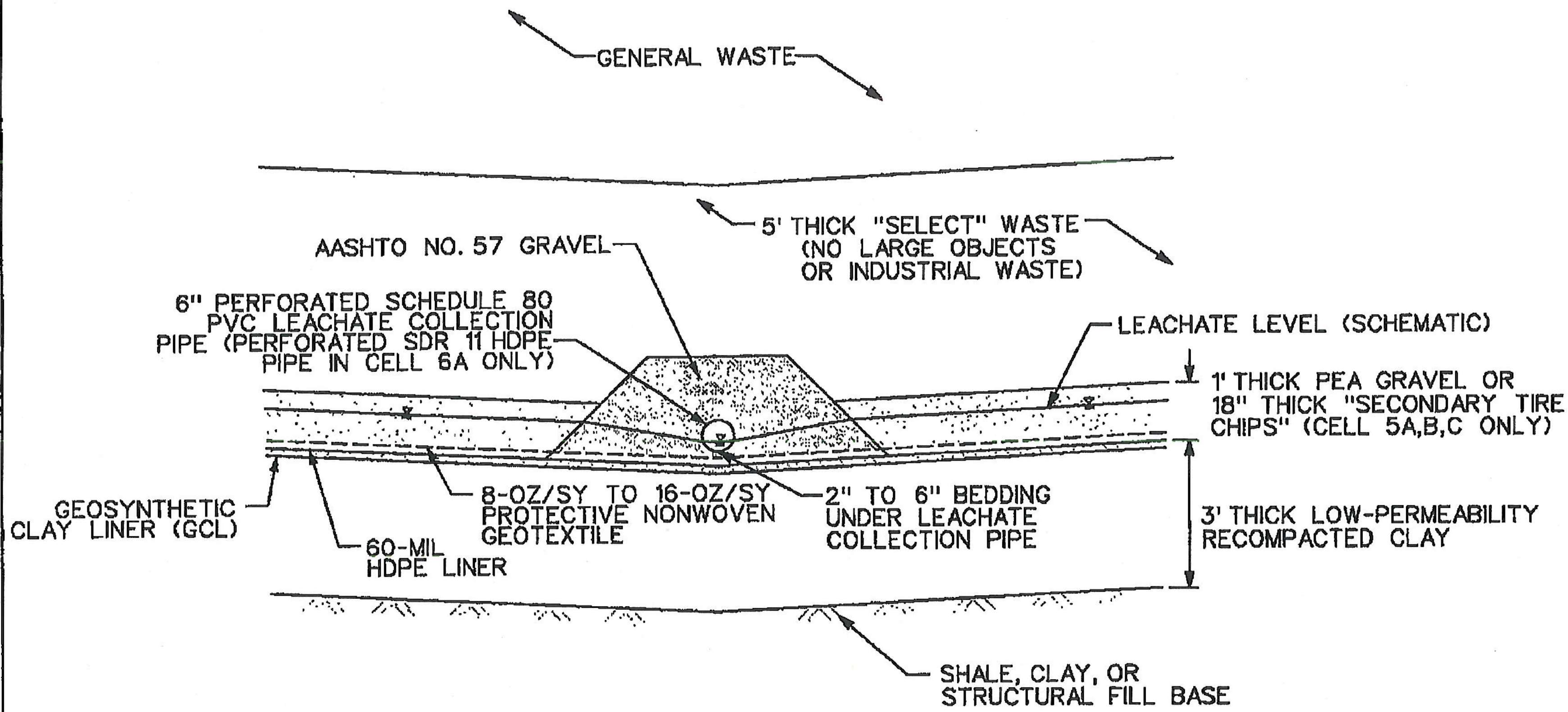
5/10/2007



NOTE: EACH CELL HAS SLIGHTLY DIFFERENT CONSTRUCTION DETAILS. THE FEATURES SHOWN HERE ARE COMMON TO EACH

EarthTech

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FIGURE 3
TYPICAL LINER SYSTEM
CELLS 5-6

COUNTYWIDE LANDFILL
ENGINEERED COMPONENTS
EVALUATION STUDY

MAY 2007

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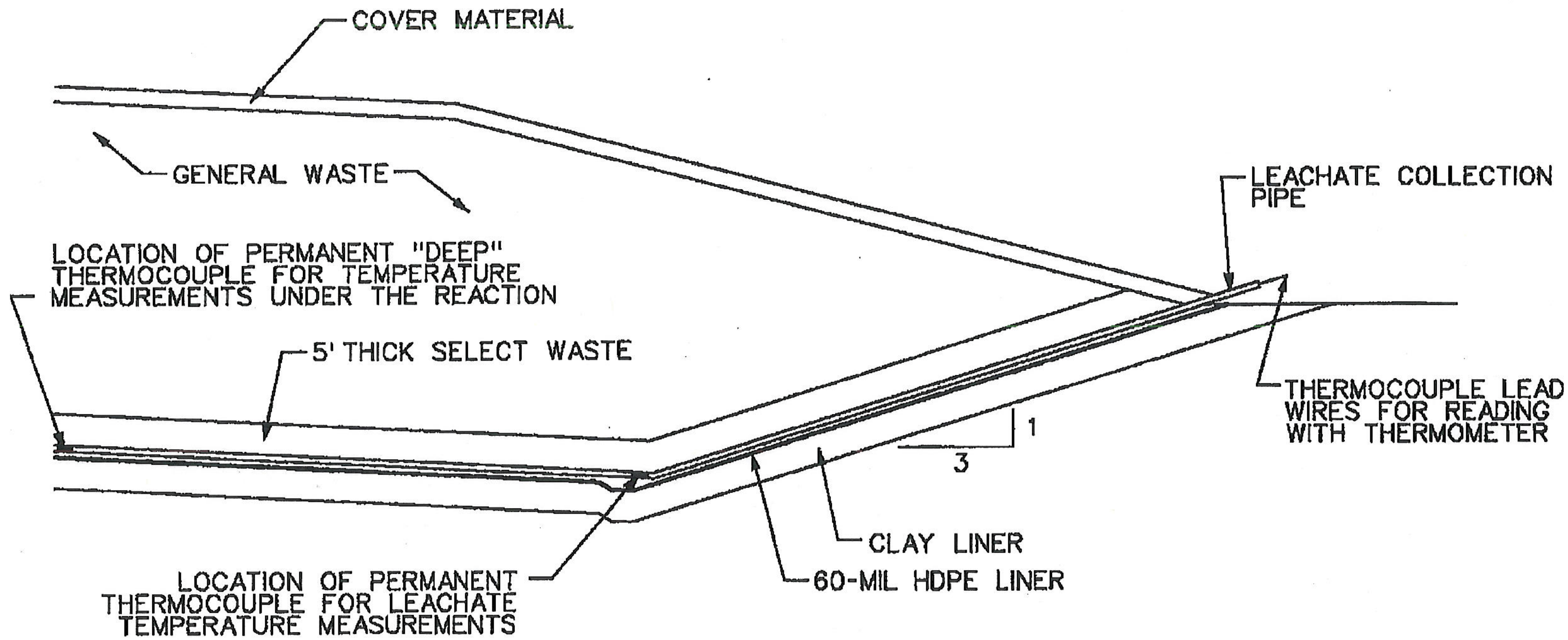

EarthTech
A tyco International Ltd. Company

FIGURE 7
SCHEMATIC OF INSTALLATION OF PERMANENT THERMOCOUPLES

COUNTYWIDE LANDFILL
ENGINEERED COMPONENTS
EVALUATION STUDY

MAY 2007

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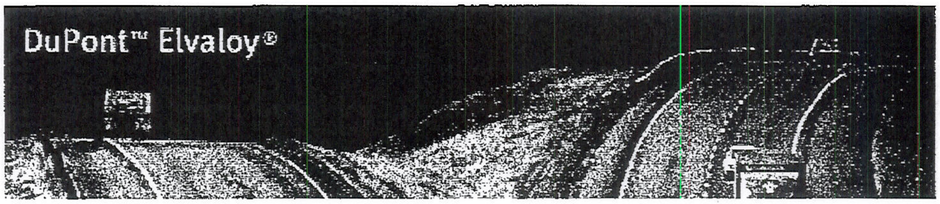
APPENDIX A

ANALYSIS OF THERMOPLASTICS USED IN FOLD AND FORM PIPE LINERS

Select Industry
- Select -



DuPont Home « Products & Services « Elvaloy « Technical Info

Analysis of Thermoplastics Used in Fold-and-Form Pipe Liners

by E. R. Griffin, Senior Technical Specialist

DuPont CompanyOf the 200,000 miles of wastewater (sewer) pipe in need of repair, more than 20,000 miles will be repaired in the next 5 years. PVC fold-and-form pipe had about 7 percent of the total rehabilitation market in 1995 and is expected to grow to 27 percent of the total by 2000.The objective of this paper is to relate plastic material properties to installation and performance properties of pipeline rehabilitation materials. The work will concentrate on plastics used in the area of fold-and-form or deform/reformed pipe liner. These plastics include polyvinyl chloride (rigid PVC), PVC modified with DuPont Elvaloy® ketone ethylene ester (KEE) resin (modified PVC), and high-density polyethylene (HDPE).This paper will show that PVC modified with Elvaloy®:

has a wider forming temperature window and installs faster and easier than polyethylene or rigid PVC;
provides a snug fit with less annular space than polyethylene or rigid PVC;
creeps less than polyethylene over the life of the liner; and
has less tendency than rigid PVC to split or crack.

"No-Dig" Fold-and-Form Pipe Liners

Rigid PVC, PVC modified with Elvaloy® , and high-density polyethylene are three principal thermoplastics used for trenchless ("no-dig") rehabilitation of wastewater pipes. Liners made of these plastics are manufactured with a cross-sectional area, then wound on large spools to be shipped to installation sites. In the field, the new liner is pulled through the host pipe, entering and exiting via existing manholes. The liner is then reformed in place using heat and pressure.This paper addresses properties of plastic that allow the material to be thermoprocessed and reduce the effects of stress introduced by thermoprocessing. Properties of interest include the liner's ability to be flexible while being installed, to be stretched and formed into the shape of the host pipe, and to maintain its strength and shape over time.

Plastic Forming or Reforming

Forming the pipe liner inside a host pipe is similar to plastic thermoforming, where plastic sheet is heated to a forming temperature and then deformed or stretched to a desired shape using vacuum or pressure. Often, the thermoformed shape is defined by a mold. Examples include blister packaging, cups, skylight bubbles and refrigerator door liners.In the pipe liner forming process, the plastic liner is heated and formed or stretched into the shape of the host pipe. The forming quality depends on the temperature, pressure, and time used by the operator, and on the forming temperature and pressure window allowed by the plastic.The forming window is determined by the polymer morphology, and by physical properties such as tensile strength and elongation. Properties important to various pipe liner processes are listed in Table 1.

Table 1. Properties for Pipe Liner Reforming Processes

Pipe Liner Process	Plastic Property
Reducing internal stresses during forming and reforming	Modulus, molecular mobility and elongation at the forming temperature
Stretching over joints and obstacles in the host pipe	Tensile strength and elongation at the forming temperature

Shrinkage, maintaining a snug fit after cooling and leaving a small annular space	Elongation at the forming temperature, the ability of the molecules to reorient, and the volume expansivity or pressure-volume-temperature relationship
Relieving internal stresses and withstanding stress during finishing and trimming	Elongation and impact resistance at ambient temperature
Strength and resistance to deformation under load over time	Viscoelastic properties and creep resistance

The plastic properties of strength, elongation, molecular mobility, volume versus temperature, and viscoelastic properties, are functions of the crystallinity or lack of crystallinity of the polymer, discussed below.

Crystalline and Amorphous Polymers

There are two broad categories of polymers: crystalline and amorphous. Polymers are considered crystalline if their molecules arrange in an orderly, laminar configuration. More accurately, these polymers are referred to as semicrystalline, because only a portion of their molecules are in a crystalline form.[5] In contrast, amorphous polymers are those that have no known order or pattern.As polymers are heated, the polymer chains gain mobility and the polymer properties go through notable transitions. One of the most significant thermal transitions is the glass transition, which occurs over a temperature range starting at the glass transition temperature (T_g). The temperature range for this transition is unique for each polymer.This glass transition relates only to the amorphous (noncrystalline) portion of polymers. At temperatures below this transition, the polymer is glasslike: It has a high flexural modulus or high stiffness. As temperatures increase through the glass transition region, the amorphous portions gain molecular mobility and change from a high-modulus (rigid) state to a lower-modulus (rubbery) state. The rate of this transition is unique for each polymer.After the glass transition, the rate of change of modulus versus temperature returns to a very flat curve. The temperature continues to increase to the crystalline melting temperature.Highly crystalline polymers, such as high-density polyethylene, remain somewhat stiff as their small amorphous regions go through their glass transition. The crystalline regions of the polymer hold the molecules in place. Because the polymer remains stiff, it can be used above its T_g without losing its form. However, as the temperature of a highly crystalline polymer continues to rise, its crystalline regions transition to a low-modulus liquid at the crystalline melt temperature (T_m).T_m is usually much higher than T_g. For example; for HDPE T_g is a very low -160°C and T_m is 134°C. For PVC, T_g is 87°C and T_m is considered 200°C. At temperatures above T_g (in the case of HDPE, anything above -160°C), a crystalline polymer can and does deform under load . . . more easily than if it were at temperatures below its T_g. As it relates to pipe liner installation, the thermal transitions and amount of crystallinity greatly affect how easily the material forms at the forming temperature, how well the internal stresses are relieved, how much the polymer shrinks, and how much the pipe liner deforms over time, or creeps.

Forming the Polymer

As plastic is heated, the polymer chains gain mobility and can be reformed into a different shape. Above their T_g, most amorphous polymers (including PVC) can begin to flow if there is sufficient pressure or load. With increasing temperatures, the polymer chains gain more mobility and can flow using less pressure. Amorphous material can retain its new shape after the temperature is dropped below T_g and the load is removed.For crystalline polymers at temperatures between T_g and T_m, chain mobility is constrained by the crystalline regions of the polymer. The crystalline structures are not fully mobile until the temperature exceeds the crystalline melting point (T_m).Polyethylene is formed mostly by melting the crystalline regions and reforming them into the new shape. The crystalline melting region for polyethylene has a wide temperature range, with a very slow increase in flow as temperature is increased. To completely reform polyethylene and relieve all the stress of the original shape, the polymer must be completely melted to a liquid by heating to 284 F (140 C) or higher.However, as polyethylene is heated above its T_m of about 273°F (134 C), it begins to flow like a liquid. Its melt viscosity at such temperature is too low for thermoforming and pipe liner forming. Thus, HDPE pipe liner forming requires a difficult balance: The polymer needs to get hot enough to relieve stress and reform crystalline regions, but stay cool enough to have sufficient melt strength to maintain pipe shape and not become a liquid. Thus the forming window is very narrow and must be carefully balanced during pipe liner forming. Complete stress relief is not possible while melt strength is maintained.In contrast, PVC is formed mostly while it is in a rubbery state, above T_g and below T_m. The high melt strength of the rubbery state makes PVC easy to thermoform. PVC modified with Elvaloy® is even easier to thermoform because it has a wider temperature window and increased melt strength.One way to study thermal transitions and polymer flow is dynamic mechanical analysis (DMA). DMA measures the storage modulus (E'), the loss modulus (E") and their ratio (E"/E'), known as tan delta of a polymer over a temperature range. The storage modulus can be thought of as the stiffness of the polymer, like flex modulus or tensile modulus. Figures 1, 2, and 3 show the DMA data for PVC, PVC modified with Elvaloy® , and HDPE.

Figure 1.

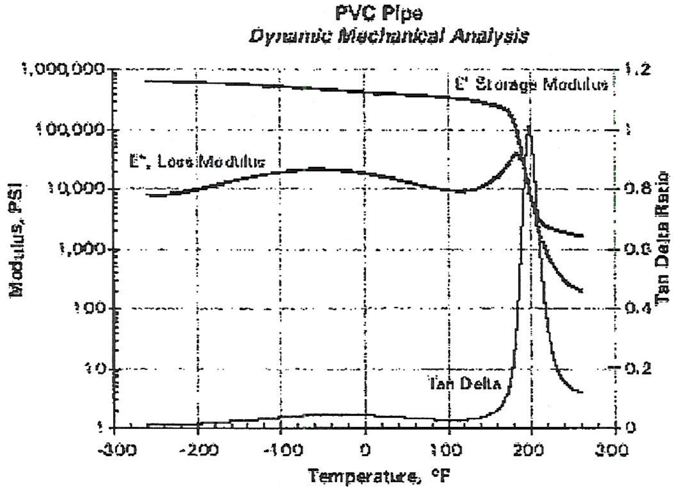


Figure 2.

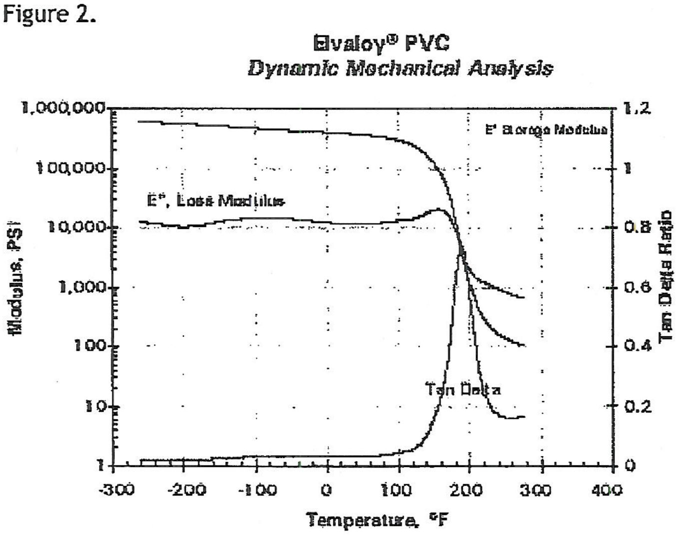


Figure 3.

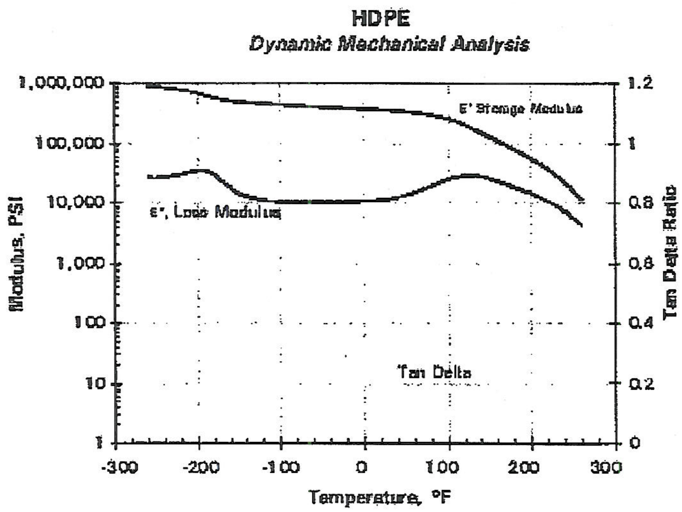
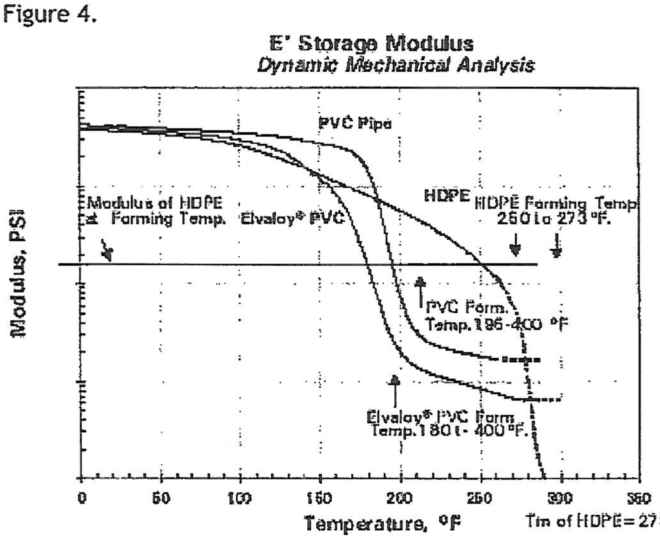


Figure 4 compares E' of PVC, PVC modified with Elvaloy®, and HDPE as temperature is increased. The modulus of HDPE is lower than both PVC types at room temperature, and then slowly curves down as the temperature increases. Because the test cannot hold a liquid sample, the HDPE test is terminated before the polymer melts at 273°F (134°C).

Figure 4.



The moduli of PVC and PVC modified with Elvaloy® are high until the resins reach their glass transition temperatures (about 180 and 155°F, respectively). The modulus drops as the temperature increases through the T_g region, and finally flattens in the rubbery state. The PVC samples are still rubbery at the melt temperature (T_m) of HDPE. It is instructive to examine the modulus of the polymers at the pipe liner forming temperatures described in ASTM standard sample preparation methods for polyethylene and PVC pipe liner. (See Table 2.)

Table 2. Pipe Liner Sample Preparation Methods [1,2]

	Sample Forming Procedure	PVC	PE
Step 1	Temp. °F (°C)	200 (93)	200 (93)
	Pressure, psi	Atmosphere	Atmosphere
	Time	15	15
Step 2	Temp. °F (°C)	200 (93)	250 (121)
	Pressure, psi	8	14.5
	Time	2	2
Step 3	Temp. °F (°C)	100 (38)	250 (121)
	Pressure, psi	8	26

	Time	Until cool	2
Step 4	Temp. °F (°C)	Not	100 (38)
	Pressure, psi	Applicable	26
	Time	--	Until cool

The minimum forming temperature can be defined as the temperature listed in Step 2. The maximum temperature is T_m. Note the modulus E' of the plastics at the forming temperatures 250 to 273°F (121 to 134°C) of HDPE, as plotted in Figure 4. PVC and PVC modified with Elvaloy® have lower modulus and flat curves of the rubbery state at these temperatures. The modulus of the HDPE is still very high and continues to drop as it reaches its melting point.One can assume that the modulus of the pipe liner during forming must be as low as the modulus of HDPE at 250°F (121°C). Therefore, Figure 4 includes a line indicating that modulus. The PVC and the PVC modified with Elvaloy® will reach the same modulus at lower temperatures: 195°F and 180°F (90°C and 82°C). The modulus of polyethylene must stay above the liquid stage at T_m 273°F (134°C).This results in a narrow forming window for the HDPE: 250 to 273°F, at a higher temperature and pressure. A narrow forming temperature window leaves little room for uncontrollable variables like groundwater temperature, water in the host pipe, and thermocouple error. The PVC-based liners have much broader temperature windows: 180 to 273 F for PVC modified with Elvaloy® and 195 to 273°F for PVC. The PVC based liners can be formed at lower pressure since the modulus can be lowered by increasing the temperature to the rubbery stage. This leaves more room for those uncontrollable variables.In addition, because the crystalline melting temperature of HDPE is not reached during forming, not all of the crystalline regions are reformed. Thus, these crystalline regions will tend to revert back to their original form and shape, which is significant for the highly crystalline HDPE. Because the temperatures during forming are above the glass transition temperatures, the amorphous regions of the polymers are relieved of internal stress and reformed. This is more significant for the amorphous PVC systems, including PVC modified with *Elvaloy*®.

Creating a Snug Pipe Liner

The PVC modified with Elvaloy® maintains a snug fit after cooling and does not move during temperature fluctuations. The reason for this is found in the way plastics cool.The molecules of crystalline polymers such as polyethylene tend to move closer to each other as they cool. This is the nature of crystallinity, giving the polymer a tight molecular matrix and some rigidity at temperatures above T_g. In contrast, amorphous polymers such as PVC do not pack closer as they cool. They gain rigidity by locking the amorphous regions into place at temperatures below their T_g.Polymer volume change during cooling is studied using pressure-volume-temperature (PVT) data, or volume expansivity. The specific volumes of the polymers were measured as the temperature was increased over the range of 86 to 375°F (30 to 190°C). Linear thermal expansion is one dimension of specific volume. Figure 5 is a plot of the specific volumes (cm3 per gram) of PVC modified with Elvaloy®, of rigid PVC dry blend, and of polyethylene pipeliner. The polyethylene curves show a dramatic change in specific volume near 266°F (130°C), which is where the polymers begin to melt.

Figure 5.

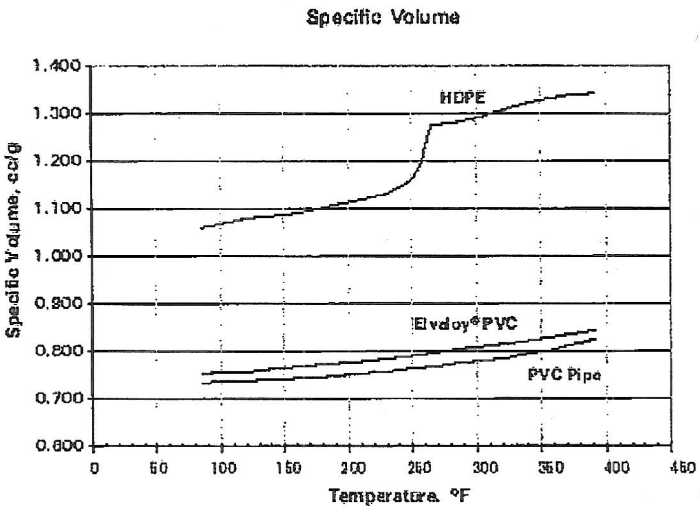


Table 3 shows the change in specific volume during cooling of HDPE and PVC samples, using the temperatures suggested in the standard sample preparation method.

Table 3. Specific Volume at Forming and Cooled Temperatures

Specific Volume	PVC with Elvaloy®	PVC	HDPE
At forming temperature	0.8 cm^3/g at 200°F (93°C)	0.75 cm^3/g at 200°F (93°C)	1.16 cm^3/g at 250°F (121°C)
At 100°F (38°C)	0.779 cm^3/g	0.736 cm^3/g	1.062 cm^3/g
Change in specific volume	2.6%	1.5%	8.4%

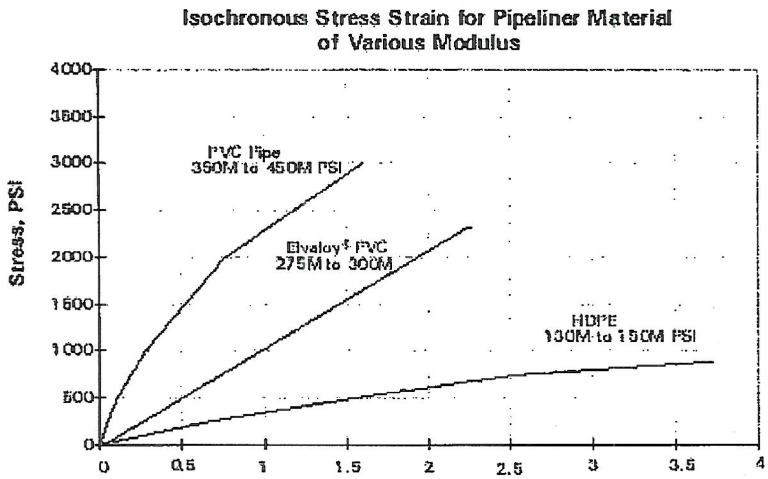
Note that the volume change of the HDPE is five times greater than the volume change of PVC and three times greater than the volume change of PVC modified with Elvaloy® . HDPE shrinkage is based on the cooling rate and change in temperature. If the cooling happens quickly (i.e., the cooling temperature is much lower than the hot HDPE), then the crystalline structure may not form well. This increases the potential for creep over time, and can lead to further shrinkage if the liner is annealed (reheated and cooled).The high rate of HDPE shrinkage can create annular space between the liner and the host pipe. The dimensional change also forces installers to wait several hours before reinstating lateral connections. This helps prevent shifts or breaks in the lateral connections as the liner finishes cooling. Often, a subsequent workday may be scheduled to complete these connections.PVC and PVC modified with Elvaloy® don't shift the way HDPE does, because the molecular structure of PVC is not crystalline and the molecules do not continue to compact. In addition, the PVC with Elvaloy® has higher melt strength and ultimate elongation at the forming temperature than rigid PVC. This allows the liner to stretch outward and conform tightly to the grooves and ridges of the host pipe; it "grabs on" to these features, helping maintain its position as it cools. The pipe designer can balance the properties of "grab on" and shrinkage by balancing the amount of Elvaloy® modifier.

PVC with Elvaloy® Will Creep Less Than HDPE

Flexural Modulus and Creep

Flexural modulus is a measure of the rigidity of a material in the flex mode. For plastics, this is measured under ASTM guidelines D790. When designing a pipe liner, the engineer uses flexural modulus to determine the liner stiffness and the critical buckling pressure. There are many references to this calculation and it will not be discussed here. This paper will address the flexural (or flex) creep modulus, flexural (or flex) creep, and their effect on the pipe liner.Flex creep is the deformation of a material over time, under flexural load. It refers to the deformation or strain of the plastic with a flexural load. Flex creep is measured using ASTM D2990: A standard flexural test sample bar is placed in horizontal clamps and constant stress or load is applied. The deflection or strain of the bar is measured at specific time intervals.Flex creep modulus is calculated from this strain versus stress data. It's a ratio of the constant stress load applied at the beginning of the test, divided by the deflection strain at the given time. Creep modulus -- whether under flexural, tensile or compression load -- is not a measure of the modulus of the material at the time the constant stress vanishes. It has been noted[3] that if a PVC tensile creep sample were to be taken off test after a period of time and tested in a tensile tester, the strength of the sample would be greater than the initial strength and the slope of the stress strain curve (modulus) would also be equal to or greater than the original slope.In order to compare the creep of materials, a design engineer often uses isochronous (equal time) creep stress strain curves. Figure 6 plots the stress versus strain at 1000 hours using literature values[9] for PVC and HDPE and DuPont data for the PVC modified with Elvaloy® . As shown, over time -- given the same stress or load -- HDPE will deform more than the PVC with Elvaloy® , and much more than the PVC.

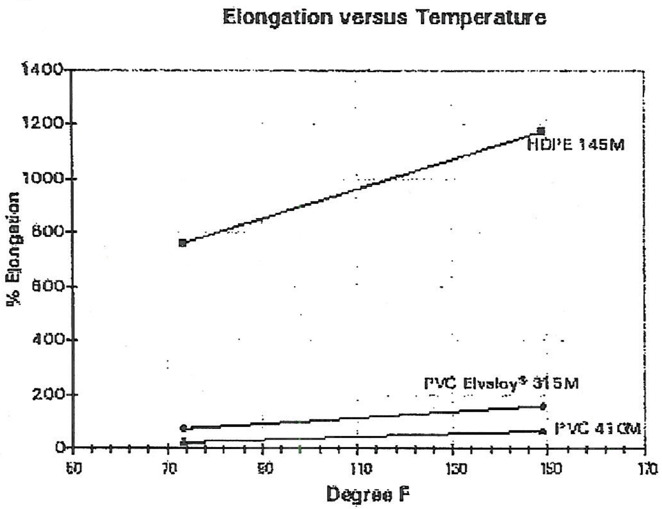
Figure 6.



Internal Stress In Plastic Pipe Liners

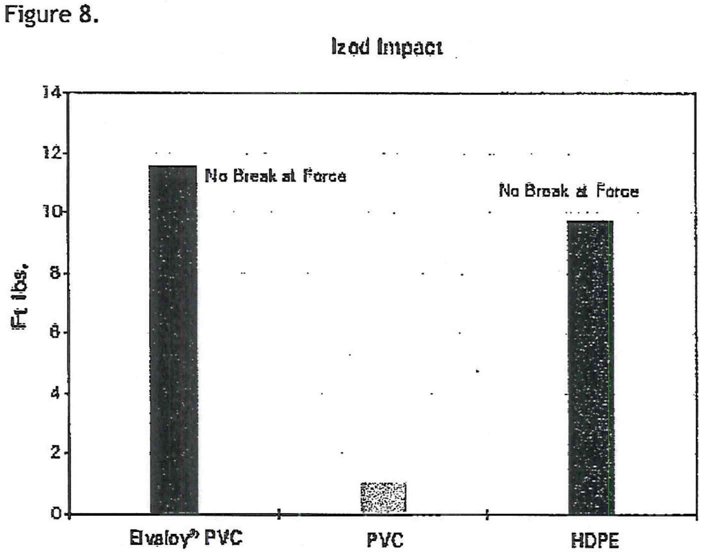
Fold-and-form pipeline rehabilitation requires a material that can withstand or relieve internal stress from the many operations it undergoes. The material is stressed again and again as it is extruded, folded, wound for shipping, pulled through the host pipe, reformed, and finally cut through to make lateral connections. It would be impractical to study and predict all the forces and stresses on the pipe liner. Therefore the material used to make the pipe liner should be designed to relieve high levels of stress.Stress relaxation and creep are often studied together. While creep is the deformation due to an applied load over time, stress relaxation is the reduction of stress of a deformed material over time under constant strain. Materials with more creep tend to reduce more applied external stress.One way to predict the ability of a plastic to relieve stress is by studying the ratio of the plastics energy loss to the plastic's energy stored. On DMA curves, these energies are referred to as the loss modulus (E") and the storage or elastic modulus (E'). The ratio E"/E', referred to tan delta, is plotted on the DMA curves in Figures 1,2 and 3.Pipe liner materials should balance E' and E" to optimize the properties needed to form the liner and relieve stress. If the loss modulus E" is too low during forming, the viscosity will be low and the material will be too weak to deform evenly. If the elasticity E' is too high during forming, there will be too much memory and higher-than-desired levels of molded-in stress.At liner forming temperatures, the PVC and the modified PVC liners are above T_g and in their elastomeric state, long before the PVC melts. (When melted E" is very low.) While cooling, the plastic goes through a gradual transition between the elastomeric and viscous phases (as indicated by the tan delta), transitioning from above T_g to below T_g. A slow transition gives the material time to settle into an unstressed condition. If the transition is too sudden, the molecules do not have as much time to relax. The broad tan delta for PVC modified with Elvaloy® indicates that this material has more time to relax than does the rigid PVC.Since HDPE is not cooled to below T_g, this argument does not apply. E' and E" are both high before the crystalline regions melt. Optimum stress relaxation occurs when the crystalline regions are melted and reformed. As mentioned earlier, HDPE will continue to relax and creep after the liner is cooled.Another way to measure of the plastics' ability to relieve stress in the operations of deforming and reforming is to measure elongation at break. Figure 7 shows the elongation measured for a rigid PVC, a PVC modified with Elvaloy® , and HDPE at room temperature and at 150 °F (65 °C). As shown, adding Elvaloy® increases the ability of the PVC to elongate. This makes it easier to process the liner through folding/forming, winding on a reel and pulling. This increase in elongation also shows that Elvaloy® helps to relieve the internal stress in the pipe liner and avoid brittle cracks of rigid PVC.The very crystalline HDPE has high strength and elongation at 150 °F (65 °C). This shows that the HDPE can relieve much of the stress placed on it, if the crystallites are not melted and reformed.

Figure 7.



Lastly, impact force is placed on the pipe liner as cuts are made for lateral line connections. Higher Izod impact properties indicate the strength to avoid splitting while being cut. Izod impact data for rigid PVC, HDPE, and PVC modified with Elvaloy® are shown in Figure 8. HDPE and PVC modified with Elvaloy® have very good impact properties compared to rigid PVC.Of course there are many factors that effect cracking. But using Elvaloy® gives these systems more ability to elongate, to relieve stress, and to withstand the impact of cutting.

Figure 8.



Conclusion

Adding Elvaloy® to a PVC pipe liner compound helps balance the liner's material properties of stiffness and stress relief. The liner installation can be completed faster, at lower reforming temperatures and pressures than when using rigid PVC or HDPE. Because Elvaloy® creates a wide operating window, the rehabilitation project is less susceptible to variations in temperatures and pressures of the process steam, or varied groundwater conditions. Modifying PVC with Elvaloy® also helps the pipe liner maintain its integrity during processing and over time, by relieving the stress and avoiding cracking, splitting and stress concentrations. PVC liners made with Elvaloy® have the widest forming window, relieve the most stress, closely conform to the host pipe, and provide a snug fit that stays properly sized and positioned inside the rehabilitated pipe.

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APPENDIX B

GEOMEMBRANE LIFETIME PREDICTION

Geosynthetic Institute
475 Kedron Avenue
Folsom, PA 19033-1208 USA
TEL (610) 522-8440
FAX (610) 522-8441

GRI GEI GII GSI GAI GCI

GRI White Paper #6

- on -

Geomembrane Lifetime Prediction:
Unexposed and Exposed Conditions

by

Robert M. Koerner, Y. Grace Hsuan and George R. Koerner
Geosynthetic Institute
475 Kedron Avenue
Folsom, PA 19033 USA

Phone (610) 522-8440
Fax (610) 522-8441

E-mails:
robert.koerner@coe.drexel.edu
grace.hsuan@coe.drexel.edu
gkoerner@dca.net

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Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions

1.0 Introduction

Without any hesitation the most frequently asked question we have had over the past 25 years' is "how long will a particular geomembrane last".* The two-part answer to the question, largely depends on whether the geomembrane is covered in a timely manner or left exposed to the site-specific environment. Before starting, however, recognize that the answer to either covered or exposed geomembrane lifetime prediction is neither easy, nor quick, to obtain. Further complicating the answer is the fact that all geomembranes are formulated materials consisting of (at the minimum), (i) the resin from which the name derives, (ii) carbon black or colorants, (iii) short-term processing stabilizers, and (iv) long-term antioxidants. If the formulation changes (particularly the additives), the predicted lifetime will also change. See Table 1 for the most common types of geomembranes and their approximate formulations.

Table 1 - Types of commonly used geomembranes and their approximate formulations (based on weight percentage)

Type	Resin	Plasticizer	Fillers	Carbon Black	Additives
HDPE	95-98	0	0	2-3	0.25-1
LLDPE	94-96	0	0	2-3	0.25-3
fPP	85-98	0	0-13	2-4	0.25-2
PVC	50-70	25-35	0-10	2-5	2-5
CSPE	40-60	0	40-50	5-10	5-15
EPDM	25-30	0	20-40	20-40	1-5

HDPE = high density polyethylene; PVC = polyvinyl chloride (plasticized)
LLDPE = linear low density polyethylene; CSPE = chlorsulfonated polyethylene
fPP = flexible polypropylene; EPDM = ethylene propylene diene terpolymer

* More recently, the same question has arisen but focused on geotextiles, geogrids, geopipe, fibers of GCLs, etc. This White Paper, however, is focused on geomembranes due to the general lack of information on the other geosynthetics.

The possible variations being obvious, one must also address the degradation mechanisms which might occur. They are as follows accompanied by some generalized commentary.

- Ultraviolet - occurs only when the geosynthetic is exposed; it will be the focus of the second part of this communication.
- Oxidation - this occurs in all polymers and is the major mechanism in polyolefins (polyethylene and polypropylene) under covered conditions.
- Ozone - this occurs in all polymers that are exposed to the environment. The site-specific environment is critical in this regard.
- Hydrolysis - this is the primary mechanism in polyesters and polyamides.
- Chemical - can occur in all polymers and can vary from water (least aggressive) to organic solvents (most aggressive).
- Radioactive - not a factor unless the polymer is exposed to radioactive materials of sufficiently high intensity to cause chain scission, e.g., high level radioactive waste materials.
- Biological - generally not a factor unless biologically sensitive additives (such as low molecular weight plasticizers) are included in the formulation.
- Stress State - a complicating factor which is site-specific and should be appropriately modeled in the incubation process.
- Temperature - clearly, the higher the temperature the more rapid the degradation of all of the above mechanisms; temperature is critical to lifetime and furthermore is the key to time-temperature-superposition which is the basis of the laboratory incubation methods which will be followed.

2.0 Lifetime Prediction: Unexposed Conditions

Lifetime prediction studies at GRI began at Drexel University under U. S. EPA contract from 1991 to 1997 and have continued under GSI consortium funding since that time. Focus to date has been on HDPE geomembranes beneath solid waste landfills due to its common use in this particular challenging application. Incubation of the coupons has been in landfill simulation cells (see Figure 1) maintained at 85, 75, 65 and 55°C. The specific conditions within these cells are oxidation beneath, chemical (water) from above, and the equivalent of 50 m of solid waste mobilizing compressive stress. Results have been forthcoming over the years insofar as three distinct lifetime stages; see Figure 2.

Stage A - Antioxidant Depletion Time

Stage B - Induction Time to Onset of Degradation

Stage C - Time to Reach 50% Degradation (Halflife)

2.1 Stage A - Antioxidant Depletion Time

The purposes of stabilizer antioxidants are to (i) prevent polymer degradation during processing, and (ii) prevent oxidation reactions from taking place during Stage A of service life, respectively. Obviously, there can only be a given amount of antioxidants in any formulation. Once the antioxidants are depleted, additional oxygen will begin to attack the polymer chains, leading to subsequent stages as shown in Figure 2. The duration of the antioxidant depletion stage depends on both the type and amount of antioxidants.

The depletion of antioxidants is the consequence of two processes: (i) chemical reactions with the oxygen diffusing into the geomembrane, and (ii) physical loss of antioxidants from the geomembrane. The chemical process involves two main functions; the scavenging of free radicals converting them into stable molecules, and the reaction with unstable hydroperoxide

(ROOH) forming a more stable substance. Regarding physical loss, the process involves the distribution of antioxidants in the geomembrane and their volatility and extractability to the site-specific environment.

Hence, the rate of depletion of antioxidants is related to the type and amount of antioxidants, the service temperature, and the nature of the site-specific environment. See Hsuan and Koerner (1998) for additional details.

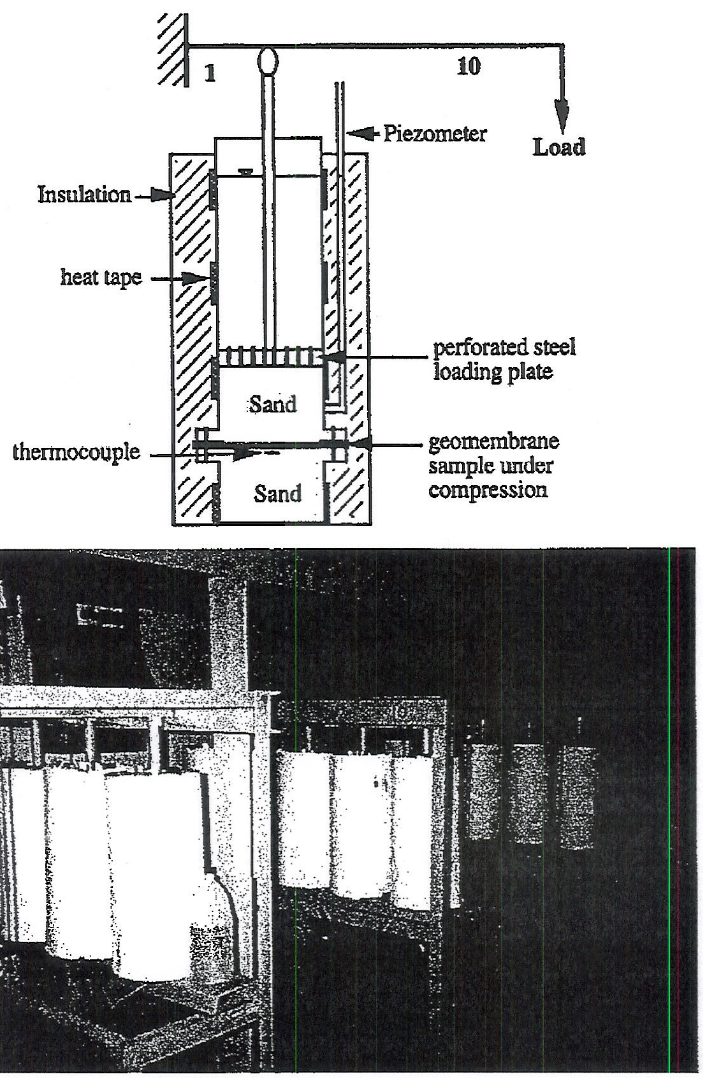


Figure 1. Incubation schematic and photograph of multiple cells maintained at various constant temperatures.

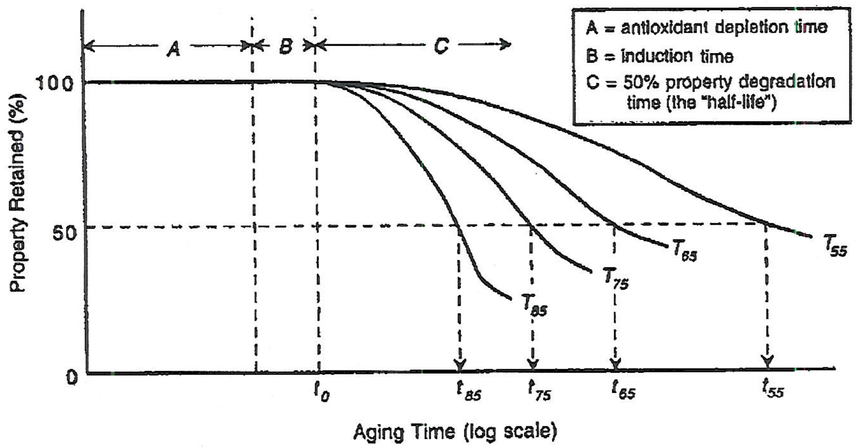


Figure 2. Three conceptual stages in chemical aging of polyolefin geomembranes.

2.2 Stage B - Induction Time to Onset of Degradation

In a pure polyolefin resin, i.e., one without carbon black and antioxidants, oxidation occurs extremely slowly at the beginning, often at an immeasurable rate. Eventually, oxidation occurs more rapidly. The reaction eventually decelerates and once again becomes very slow. This progression is illustrated by the S-shaped curve of Figure 3(a). The initial portion of the curve (before measurable degradation takes place) is called the induction period (or induction time) of the polymer. In the induction period, the polymer reacts with oxygen forming hydroperoxide (ROOH), as indicated in Equations (1)-(3). However, the amount of ROOH in this stage is very small and the hydroperoxide does not further decompose into other free radicals which inhibits the onset of the acceleration stage.

In a stabilized polymer such as one with antioxidants, the accelerated oxidation stage takes an even longer time to be reached. The antioxidants create an additional depletion time stage prior to the onset of the induction time, as shown in Figure 3(b).

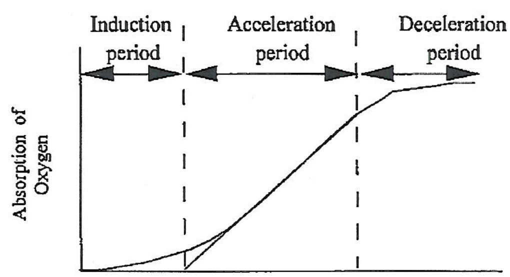
$$RH \rightarrow R\bullet + H\bullet \qquad (1)$$

(aided by energy or catalyst residues in the polymer)

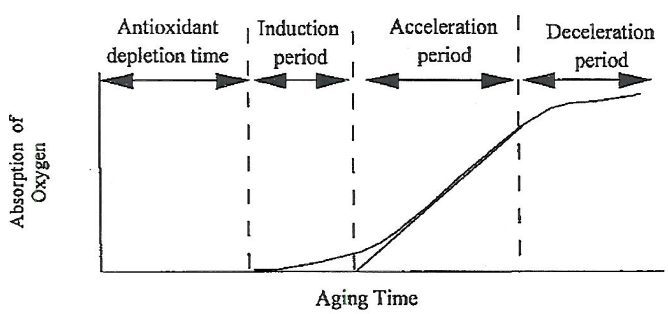
$$R\bullet + O2 \rightarrow ROO\bullet \qquad (2)$$

$$ROO\bullet + RH \rightarrow ROOH + R\bullet \qquad (3)$$

In the above, RH represents the polyethylene polymer chains; and the symbol "•" represents free radicals, which are highly reactive molecules.



(a) Pure unstabilized polyethylene



(b) stabilized polyethylene

Figure 3. Curves illustrating various stages of oxidation.

2.3 Stage C - Time to Reach 50% Degradation (Halflife)

As oxidation continues, additional ROOH molecules are being formed. Once the concentration of ROOH reaches a critical level, decomposition of ROOH begins, leading to a substantial increase in the amount of free radicals, as indicated in Equations (4) to (6). The additional free radicals rapidly attack other polymer chains, resulting in an accelerated chain reaction, signifying the end of the induction period, Rapopport and Zaikov (1986). This indicates that the concentration of ROOH has a critical control on the duration of the induction period.

$$ROOH \rightarrow RO\bullet\ OH\bullet \text{ (aided by energy)} \quad (4)$$

$$RO\bullet + RH \rightarrow ROH + R\bullet \quad (5)$$

$$OH\bullet + RH \rightarrow H2O + R\bullet \quad (6)$$

A series of oxidation reactions produces a substantial amount of free radical polymer chains (R•), called alkyl radicals, which can proceed to further reactions leading to either cross-linking or chain scission in the polymer. As the degradation of polymer continues, the physical and mechanical properties of the polymer start to change. The most noticeable change in physical properties is the melt index, since it relates to the molecular weight of the polymer. As for mechanical properties, both tensile break stress (strength) and break strain (elongation) decrease. Ultimately, the degradation becomes so severe that all tensile properties start to change (tear, puncture, burst, etc.) and the engineering performance is jeopardized. This signifies the end of the so-called "service life" of the geomembrane.

Although quite arbitrary, 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". It should be noted that even at halflife, the material still exists and can function, albeit at a decreased performance level with a factor-of-safety lower than the initial design value.

2.4 Summary of Lifetime Research-to-Date

Stage A, that of antioxidant depletion for HDPE geomembranes as required in the GRI-GM13 Specification, has been well established by our own research and corroborated by others, e.g., Sangram and Rowe (2004). The GRI data for Standard and High Pressure Oxidative Induction Time (OIT) is given in Table 2. The values are quite close to one another. Also, as expected, the lifetime is strongly dependent on the service temperature; with the higher the temperature the shorter the lifetime.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (yrs.)		Stage "B" (yrs.)	Stage "C" (yrs.)		Total Lifetime (ave. values)
	Std OIT	HP-OIT	Field Data	(max.)	(min.)	
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

Notes: Stage "A" measured values from Hsuan and Guan (1997) research via GRI
Stage "B" estimated values from field samples by GRI
Stage "C" literature values from Gedde, et al. (1994)

Stage "B", that of induction time, has been obtained by comparing 30-year old polyethylene water and milk containers (containing no long-term antioxidants) with currently produced containers. The data shows that degradation is just beginning to occur as evidenced by slight changes in break strength and elongation, but not in yield strength and elongation. The lifetime for this stage is also given in Table 2.

Stage "C", the time for 50% change of mechanical properties is given in Table 2 as well. The data depends on the activation energy, or slope of the Arrhenius curve, which is very sensitive to material and experimental techniques. The data is from Gedde, et al. (1994) which is typical of the HDPE resin used for gas pipelines.

Summarizing Stages A, B, and C, it is seen in Table 2 that the halflife of covered HDPE geomembranes (formulated according to the current GRI-GM13 Specification) is estimated to be 449-years at 20°C. This, of course, brings into question the actual temperature for a covered geomembrane such as beneath a solid waste landfill. Figure 4 presents multiple thermocouple monitoring data of a municipal waste landfill liner in Pennsylvania for over 10-years, Koerner and Koerner (2005). Note that for 6-years the temperature was approximately 20°C. At that time and for the subsequent 4-years the temperature increased to approximately 30°C. Thus, the halflife of this geomembrane is predicted to be from 270 to 449 years within this temperature range. The site is still being monitored, see Koerner and Koerner (2005).

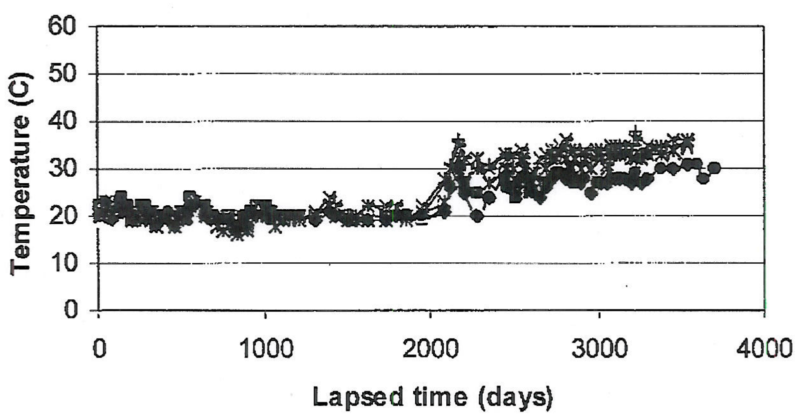


Figure 4. Long-term monitoring of an HDPE liner beneath a municipal solid waste landfill in Pennsylvania.

2.5 Lifetime of Other Covered Geomembranes

By virtue of its widespread use as liners for solid waste landfills, HDPE is by far the widest studied type of geomembrane. Note that in most countries (other than the U.S.), HDPE is the required geomembrane type for solid waste containment. Some commentary on other-than HDPE geomembranes (recall Table 1) follows:

2.5.1 Linear Low Density Polyethylene (LLDPE) geomembranes

The nature of the LLDPE resin and its formulation is very similar to HDPE. The fundamental difference is that LLDPE is a lower density, hence lower crystallinity, than HDPE; e.g., 10% versus 50%. This has the effect of allowing oxygen to diffuse into the polymer structure quicker, and likely decreases Stages A and C. How much is uncertain since no data is available, but it is felt that the lifetime of LLDPE will be somewhat reduced with respect to HDPE.

2.5.2 Plasticizer migration in PVC geomembranes

Since PVC geomembranes necessarily have plasticizers in their formulations so as to provide flexibility, the migration behavior must be addressed for this material. In PVC the plasticizer bonds to the resin and the strength of this bonding versus liquid-to-resin bonding is significant. One of the key parameters of a stable long-lasting plasticizer is its molecular weight. The higher the molecular weight of the plasticizer in a PVC formulation, the more durable will be the material. Conversely, low molecular weight plasticizers have resulted in field failures even under covered conditions. See Miller, et al. (1991), Hammon, et al. (1993), and Giroud and Tisinger (1994) for more detail in this regard.

2.5.3 Crosslinking in EPDM and CSPE geomembrnaes

The EPDM geomembranes mentioned in Table 1 are crosslinked thermoset materials. The oxidation degradation of EPDM takes place in either ethylene or propylene fraction of the co-polymer via free radical reactions, as expressed in Figure 5, which are described similarly by Equations (4) to (6).

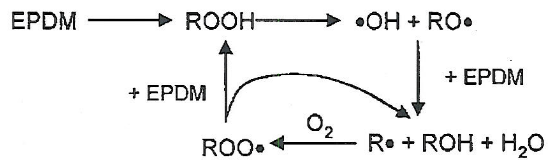


Figure 5. Oxidative degradation of crosslinked EPDM geomembranes, (Wang and Qu, 2003).

For CSPE geomembranes, the degradation mechanism is dehydrochlorination by losing chlorine and generating carbon-carbon double bonds in the main polymer chain, as shown in Figure 6. The carbon-carbon double bonds become the preferred sites for further thermodegradation or cross-linking in the polymer, leading to eventual brittleness of the geomembrane.

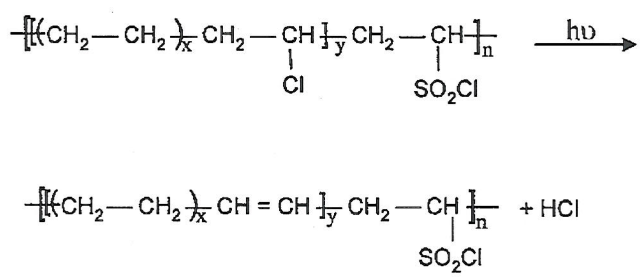


Figure 6. Dechlorination degradation of crosslinked CSPE geomembranes (Chailan, et al., 1995).

Neither EPDM nor CSPE has had a focused laboratory study of the type described for HDPE reported in the open literature. Most of lifetime data for these geomembranes is antidotal by virtue of actual field performance. Under covered conditions, as being considered in this section, there have been no reported failures by either of these thermoset polymers to our knowledge.

3.0 Lifetime Prediction: Exposed Conditions

Lifetime prediction of exposed geomembranes have taken two very different pathways; (i) prediction from anecdotal feedback and field performance, and (ii) from laboratory weathermometer predictions.

3.1 Field Performance

There is a large body of anecdotal information available on field feedback of exposed geomembranes. It comes form two quite different sources, i.e., dams in Europe and flat roofs in the USA.

Regarding exposed geomembranes in dams in Europe, the original trials were using 2.0 mm thick polyisobutylene bonded directly to the face of the dam. There were numerous problems encountered as described by Scuero (1990). Similar experiences followed using PVC geomembranes. In 1980, a geocomposite was first used at Lago Nero which had a 200 g/m^2 nonwoven geotextile bonded to the PVC geomembrane. This proved quite successful and led to the now-accepted strategy of requiring drainage behind the geomembrane. In addition to thick nonwoven geotextiles, geonets, and geonet composites have been successful. Currently over 50 concrete and masonry dams have been rehabilitated in this manner and are proving successful for over 30-years of service life. The particular type of PVC plasticized geomembranes used for these dams is proving to be quite durable. Tests by the dam owners on residual properties show only nominal changes in properties, Cazzuffi (1998). As indicated in Miller, et al. (1991) and Hammond, et al. (1993), however, different PVC materials and formulations result in very different behavior; the choice of plasticizer and the thickness both being of paramount importance.

Regarding exposed geomembranes in flat roofs, past practice in the USA is almost all with EPDM and CSPE and, more recently, with fPP. Manufacturers of these geomembranes regularly warranty their products for 20-years and such warrants appear to be justified. EPDM and CSPE, being thermoset or elastomeric polymers, can be used in dams without the necessity of having seams by using vertical attachments spaced at 2 to 4 m centers, see Scuero and Vaschetti (1996). Conversely, fPP can be seamed by a number of thermal fusion methods. All of these geomembrane types have good conformability to rough substrates as is typical of concrete and masonry dam rehabilitation. It appears as though experiences (both positive and negative) with geomembranes in flat roofs should be transferred to all types of waterproofing in civil engineering applications.

3.2 Laboratory Weatherometer Predictions

For an accelerated simulation of direct sunlight using a laboratory weatherometer one usually considers a worst-case situation which is the solar maximum condition. This condition consists of global, noon sunlight, on the summer solstice, at normal incidence. It should be recognized that the UV-A range is the target spectrum for a laboratory device to simulate the naturally occurring phenomenon, see Hsuan and Koerner (1993), and Suits and Hsuan (2001).

The Xenon Arc Weatherometer (ASTM G155) was introduced in Germany in 1954. There are two important features; the type of filters and the irradiance settings. Using a quartz inner and borosilicate outer filter (quartz/boro) results in excessive low frequency wavelength degradation. The more common borosilicate inner and outer filters (boro/boro) shows a good correlation with solar maximum conditions, although there is an excess of energy below 300 nm wavelength. Irradiance settings are important adjustments in shifting the response although they do not eliminate the portion of the spectrum below 300 nm frequency. Nevertheless, the Xenon

Arc weatherometer is commonly used method for exposed lifetime prediction of all types of geosynthetics.

UV Fluorescent Lamps (ASTM G154) are an alternative type of accelerated laboratory test device which became available in the early 1970's. They reproduce the ultraviolet portion of the sunlight spectrum but not the full spectrum as in Xenon Arc weatherometers. Earlier FS-40 and UVB-313 lamps give reasonable short wavelength output in comparison to solar maximum. The UVA-340 lamp was introduced in 1987 and its response is seen to reproduce ultraviolet light quite well. This device (as well as other types of weatherometers) can handle elevated temperature and programmed moisture on the test specimens.

Research at the Geosynthetic Institute (GSI) is actively pursuing both Xenon and UV Fluorescent devices on a wide range of geomembranes. Table 3 gives the geomembranes being incubated and the current number of hours of exposure.

Table 5 - Details of the GSI laboratory exposed weatherometer study on various types of geomembranes

Geomembrane Type	Thickness (mm)	UV Fluorescent Exposure*	Xenon Exposure*	Comment
1. HDPE (GM13)	1.50	8000 hrs.	6600 hrs.	Basis of GRI-GM13 Spec
2. LLDPE (GM17)	1.00	8000	6600	Basis of GRI-GM-17 Spec
3. PVC (No. Amer.)	0.75	8000	6600	Low Mol. Wt. Plasticizer
4. PVC (Europe)	2.50	7500	6600	High Mol. Wt. Plasticizer
5. fPP (BuRec)	1.00	2745**	4416**	Field Failure at 26 mos.
6. fPP-R (Texas)	0.91	100	100	Field Failure at 8 years
7. fPP (No. Amer.)	1.00	7500	6600	Expected Good Performance

*As of 12 July 2005 exposure is ongoing
**Light time to reach halflife of break and elongation

3.3 Laboratory Weatherometer Acceleration Factors

The key to validation of any laboratory study is to correlate results to actual field performance. For the nonexposed geomembranes of Section 2 such correlations will take hundreds of years for properly formulated products. For the exposed geomembranes of Section

3, however, the lifetimes are significantly shorter and such correlations are becoming possible. In particular, Geomembrane #5 (flexible polypropylene) of Table 3 was an admittedly poor geomembrane formulation which failed in 26 months of exposure at El Paso, Texas, USA. The reporting of this failure is available in the literature, Comer, et al. (1998). Note that for both UV Fluorescent and Xenon Arc laboratory testing of this material, failure (halflife to 50% reduction in strength and elongation) occurred at 2745 and 4416 hours, respectively. The comparative analysis of laboratory and field for this case history allows for the obtaining of acceleration factors for the two incubation devices.

3.3.1 Comparison between field and UV Fluorescent weatherometer

The light source used in the UV fluorescent weatherometer is UVA with wavelengths from 295-400 nm. In addition, the intensity of the radiation is controlled by the Solar Eye irradiance control system. The UV energy output throughout the test is 68.25 W/m^2.

The time of exposure to reach 50% elongation at break

= 2745 hr. of light
= 9,882,000 seconds

Total energy in MJ/m^2 = 68.25 W/m^2 × 9,882,000
= 674.4 MJ/m^2

The field site was located at El Paso, Texas. The UVA radiation energy (295-400 nm) at this site is estimated based on data collected by the South Florida Testing Lab in Arizona (which is a similar atmospheric location). For 26 months of exposure, the accumulated UV radiation energy is 724 MJ/m^2 which is very close to that generated from the UV fluorescent weatherometer. Therefore, direct comparison of the exposure time between field and UV fluorescent is acceptable.

Field time = 26 Months vs. Fluorescent UV light time: = 3.8 Months Thus, the acceleration factor is 6.8.

3.3.2 Comparison between field and Xenon Arc weatherometer

The light source of the Xenon Arc weatherometer simulates almost the entire sunlight spectrum from 250 to 800 nm. Depending of the age of the light source and filter, the solar energy ranges from 340.2 to 695.4 W/m^2, with the average value being 517.8 W/m^2.

The time of exposure to reach 50% elongation at break

= 4416 hr. of light
= 15,897,600 seconds

Total energy in MJ/m^2 = 517.8 W/m^2 × 15,897,600
= 8232 MJ/m^2

The solar energy in the field is again estimated based on data collected by the South Florida Testing Lab in Arizona. For 26 months of exposure, the accumulated solar energy (295-800 nm) is 15,800 MJ/m^2, which is much higher than that from the Xenon Arc weatherometer. Therefore, direct comparison of halflives obtained from the field and Xenon Arc weatherometer is not anticipated to be very accurate. However, for illustration purposes the acceleration factor based on Xenon Arc weatherometer would be as follows:

Field vs. Xenon Arc : Thus, the acceleration factor is 4.3.
= 26 Months = 6.1 Months

4.0 Summary and Recommendations

This White Paper has described research on the geomembrane type which has had the majority of research effort, that being nonexposed HDPE used in landfill applications. While this material promises service lifetime of hundreds of years, the elevated temperatures of exposed or nearly exposed geomembranes in other applications (dams, canals, reservoirs, etc.) is expected to be greatly reduced. It was shown that HDPE decreases its predicted halflife from 449-years at 20°C, to 73-years at 40°C. Other geomembrane types (LLDPE, PVC, EPDM and CSPE) have had essentially no focused effort on lifetime prediction of the type described herein. All are candidates for additional research in this regard.

Exposed geomembrane lifetime was addressed from the perspective of field performance which is very unequivocal. Experience in Europe, mainly with relatively thick PVC containing high molecular weight plasticizers, has given 25-years of service and the geomembranes are still in use. Experience in the USA with exposed geomembranes on flat roofs, mainly with EPDM and CSPE, has given 20^{+}-years of service. The newest geomembrane type in such applications is fPP which currently carries similar warranties. To be noted, however, is that degradation is a very slow process and every time a formulation changes there is uncertainty as to its long-time field performance versus the previous formulation.

Alternatively, exposed geomembrane lifetime can be addressed by using accelerating laboratory weatherometers. GSI is fully involved in such an activity using UV Fluorescent and Xenon Arc weatherometers. Two types of polyethylene, two PVCs, and three fPP geomembranes (seven in total) are being incubated for sufficient time to reach their respective lifetimes. One type of fPP has reached this level and correlation to actual field failure time is reasonable. Analysis of this (poorly formulated) geomembrane results in acceleration factors of 6.8 for UV Fluorescent, and 4.3 for Xenon Arc devices. Based on such acceleration factors, for 20-year lifetime exposed geomembranes typical laboratory weatherometer exposure will be 3-years, or longer. As noted in Table 2 such testing is ongoing and will be continued so as to report our findings at a future date. In this regard we are proceeding as follows so as to develop the required confidence needed for use of geomembranes in long-term, permanent, systems.

(i) Extend HDPE laboratory studies on nonexposed geomembranes to other polymer types such as PVC, LLDPE, fPP, EPDM and CSPE.

(ii) Evaluate, to the extent possible, various additives particularly antioxidants in polyolefins (HDPE, LLDPE and fPP) and plasticizers in PVC.

(iii) Document and analyze geomembrane dam rehabilitation in Europe (and elsewhere) with particular emphasis on durability.

(iv) Document and analyze geomembrane use in flat roofs and other exposed applications, e.g., pond and reservoir liners as well as canal liners.

(v) Initiate a broad research program on lifetime prediction of exposed geomembranes (of all types and formulations) using laboratory weatherometers such as the ongoing study described herein.

Acknowledgements

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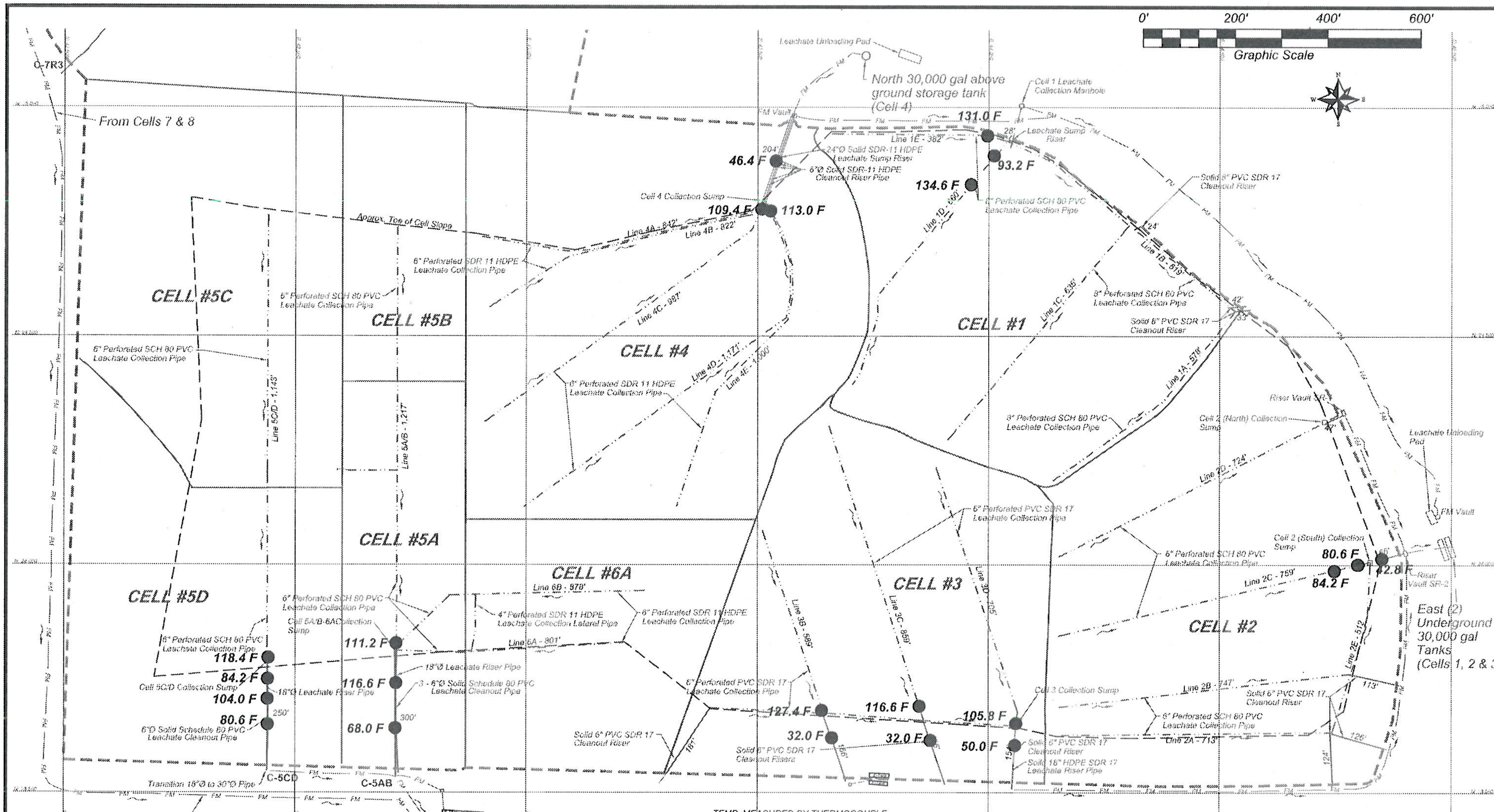


LEGEND NOTES:

1.) Leachate collection system features in Cells 1, 2, 3, 4, 5A, 5B, 5C, 5D & 6A were compiled from Bair, Goodie and Associates, Inc. "Leachate Management System" record drawings.

2.) Lengths shown for leachate collection pipes are slope corrected.

NOTE 1: THE MAXIMUM REACH FOR THIS INVESTIGATION WAS 300'. THE CABLE USED TO ADVANCE THE THERMOCOUPLE WAS NOT STIFF ENOUGH TO NEGOTIATE SOME BENDS, OR PUSH ALONG SOME FLAT CELL FLOORS.

NOTE 2: SEE TABLE 2 FOR COMPLETE LIST OF DATA

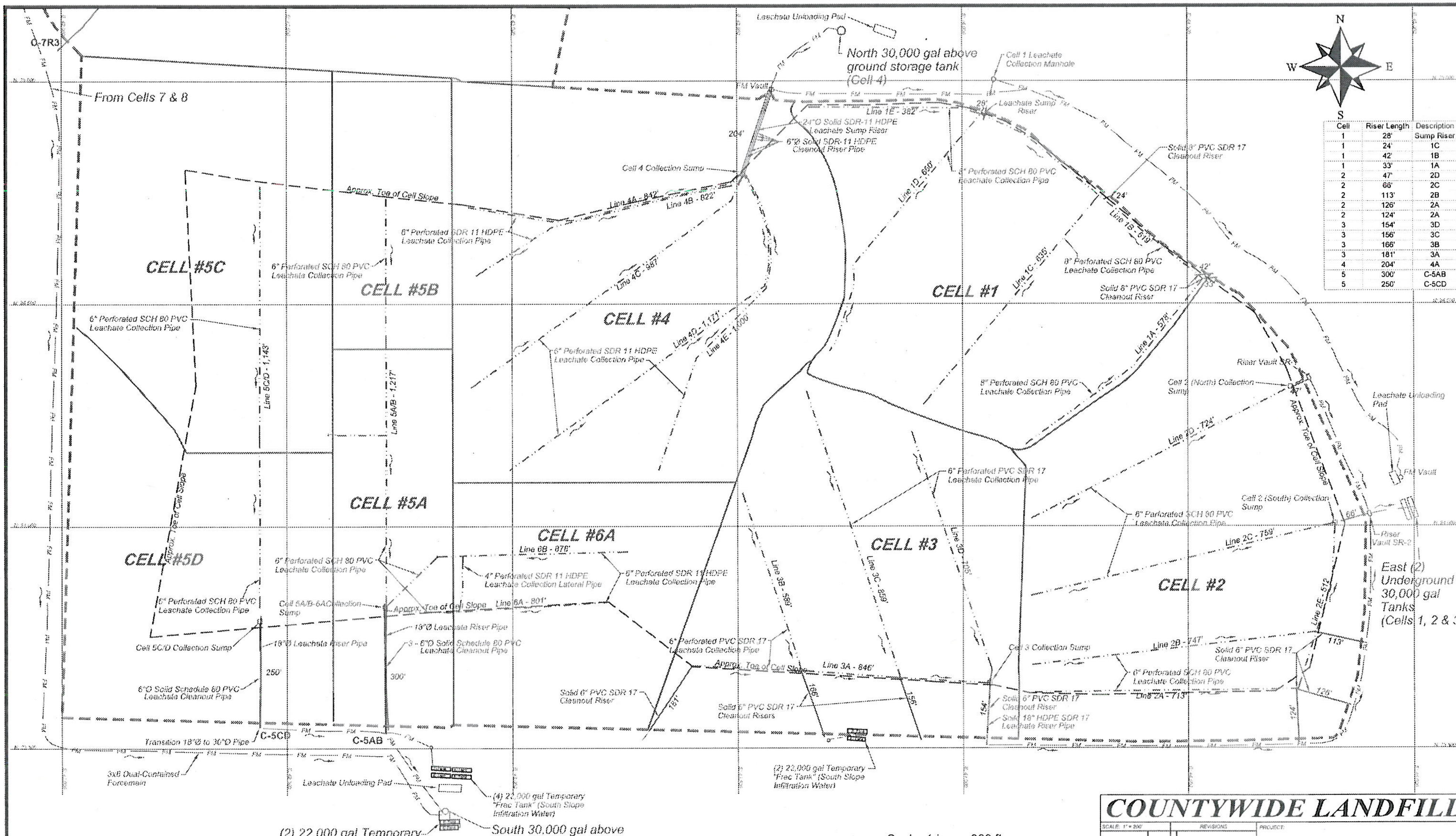
COUNTYWIDE LANDFILL

PROJECT: ENGINEERED COMPONENT EVALUATION STUDY

FIGURE TITLE: FEB. 2007 THERMOCOUPLE STUDY

EarthTech — A tyco International Ltd. Company

FIG. 5



Cell	Riser Length	Description Sump Riser
1	28'	1C
1	24'	1C
1	42'	1B
1	33'	1A
2	47'	2D
2	66'	2C
2	113'	2B
2	126'	2A
2	124'	2A
3	154'	3D
3	156'	3C
3	166'	3B
3	181'	3A
4	204'	4A
5	300'	C-5AB
5	250'	C-5CD

LEGEND NOTES:

1.) Leachate collection system features in Cells 1, 2, 3, 4, 5A, 5B, 5C, 5D & 6A were complied from Bair, Goodie and Associates, Inc. "Leachate Management System" record drawings.

2.) Lengths shown for leachate collection pipes are slope corrected.

COUNTYWIDE LANDFILL

PROJECT: ENGINEERED COMPONENT EVALUATION STUDY

FIGURE TITLE: CELL 1-6 LAYOUT AND CELL LIMITS

FIG. 1

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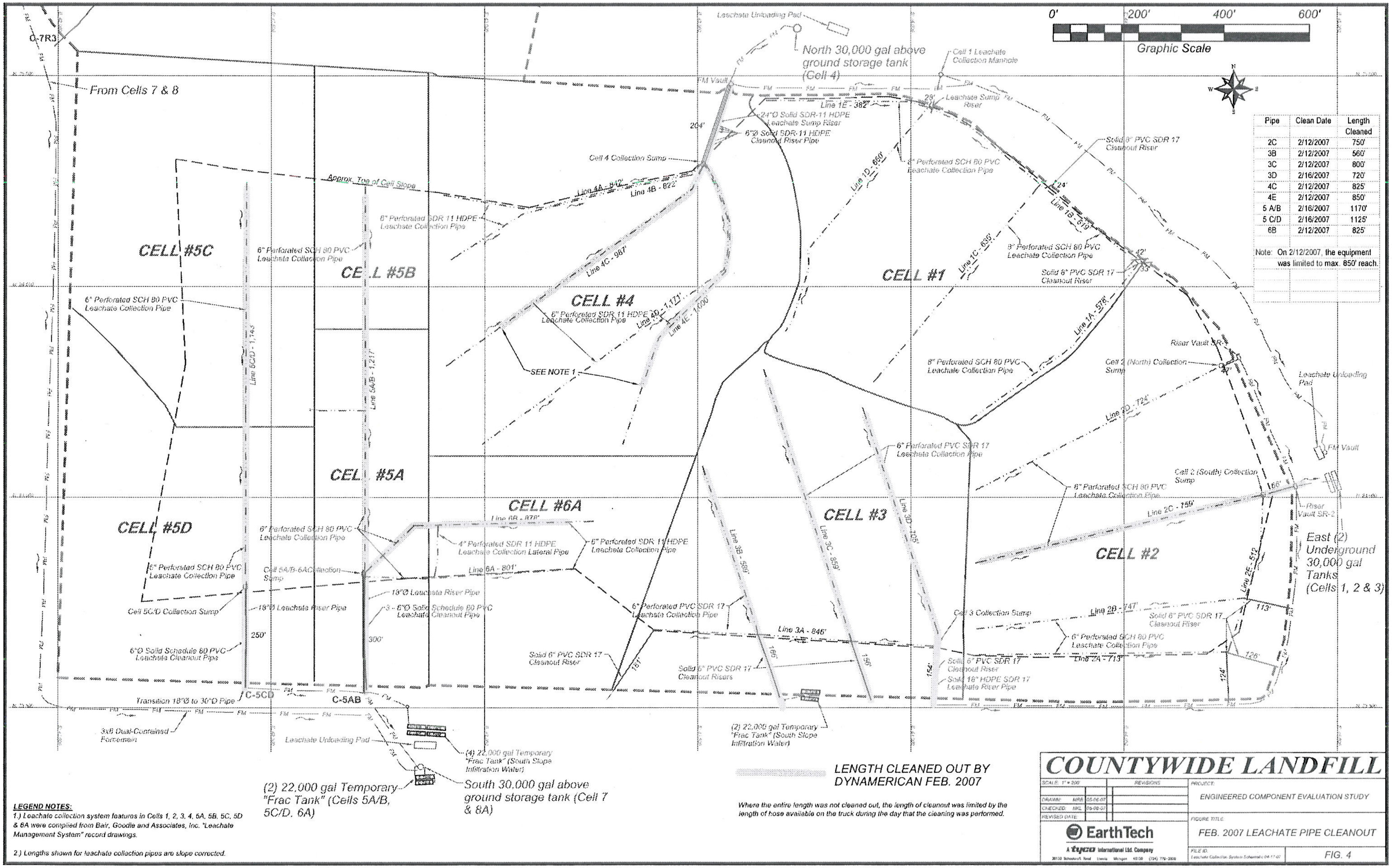

Pipe	Clean Date	Length Cleaned
2C	2/12/2007	750'
3B	2/12/2007	560'
3C	2/12/2007	800'
3D	2/16/2007	720'
4C	2/12/2007	825'
4E	2/12/2007	850'
5 A/B	2/16/2007	1170'
5 C/D	2/16/2007	1125'
6B	2/12/2007	825'

Note: On 2/12/2007, the equipment was limited to max. 850' reach.

LEGEND NOTES:

1.) Leachate collection system features in Cells 1, 2, 3, 4, 5A, 5B, 5C, 5D & 6A were complied from Bair, Goodie and Associates, Inc. "Leachate Management System" record drawings.

2.) Lengths shown for leachate collection pipes are slope corrected.

COUNTYWIDE LANDFILL

PROJECT: ENGINEERED COMPONENT EVALUATION STUDY

FIGURE TITLE: FEB. 2007 LEACHATE PIPE CLEANOUT

EarthTech

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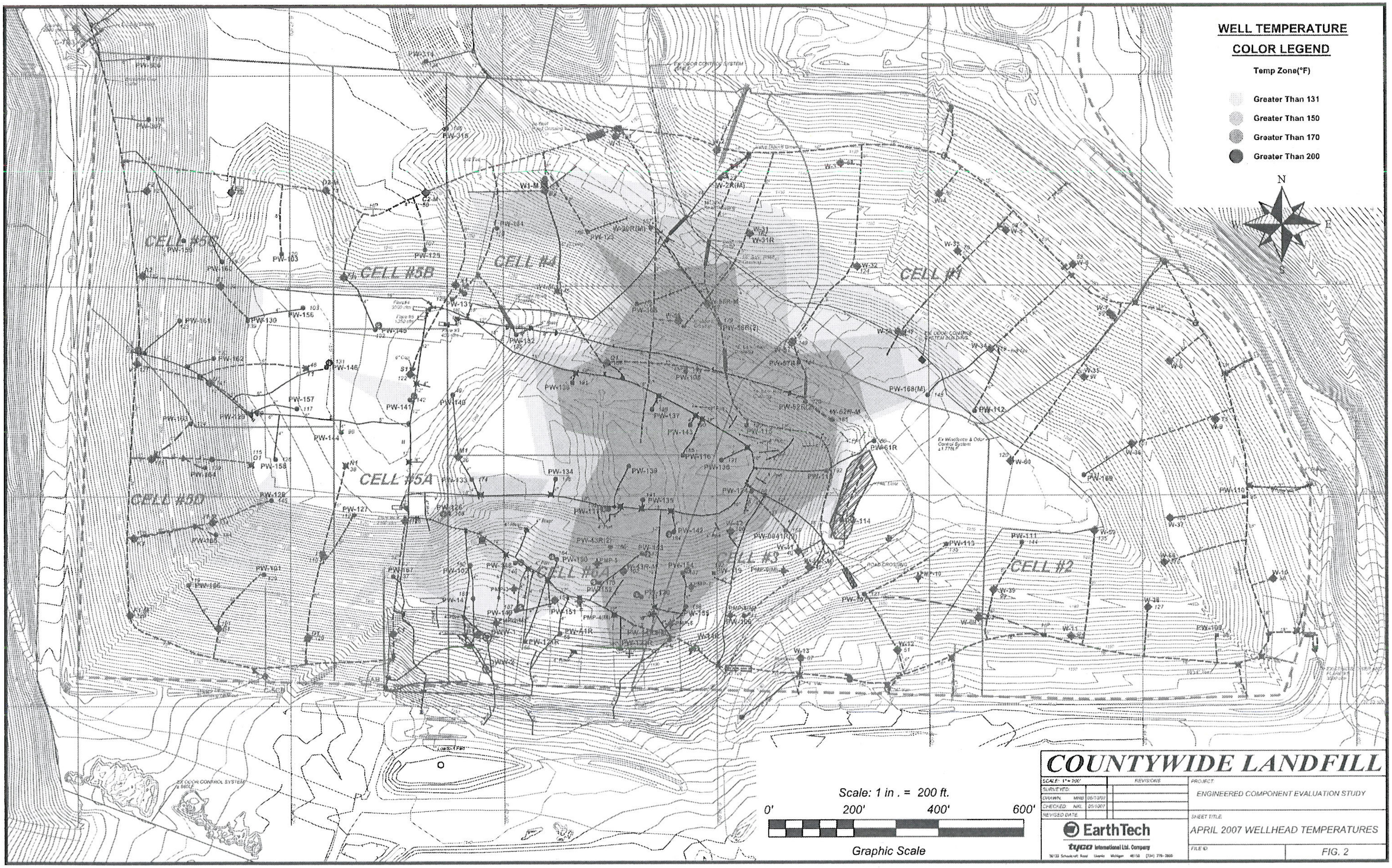
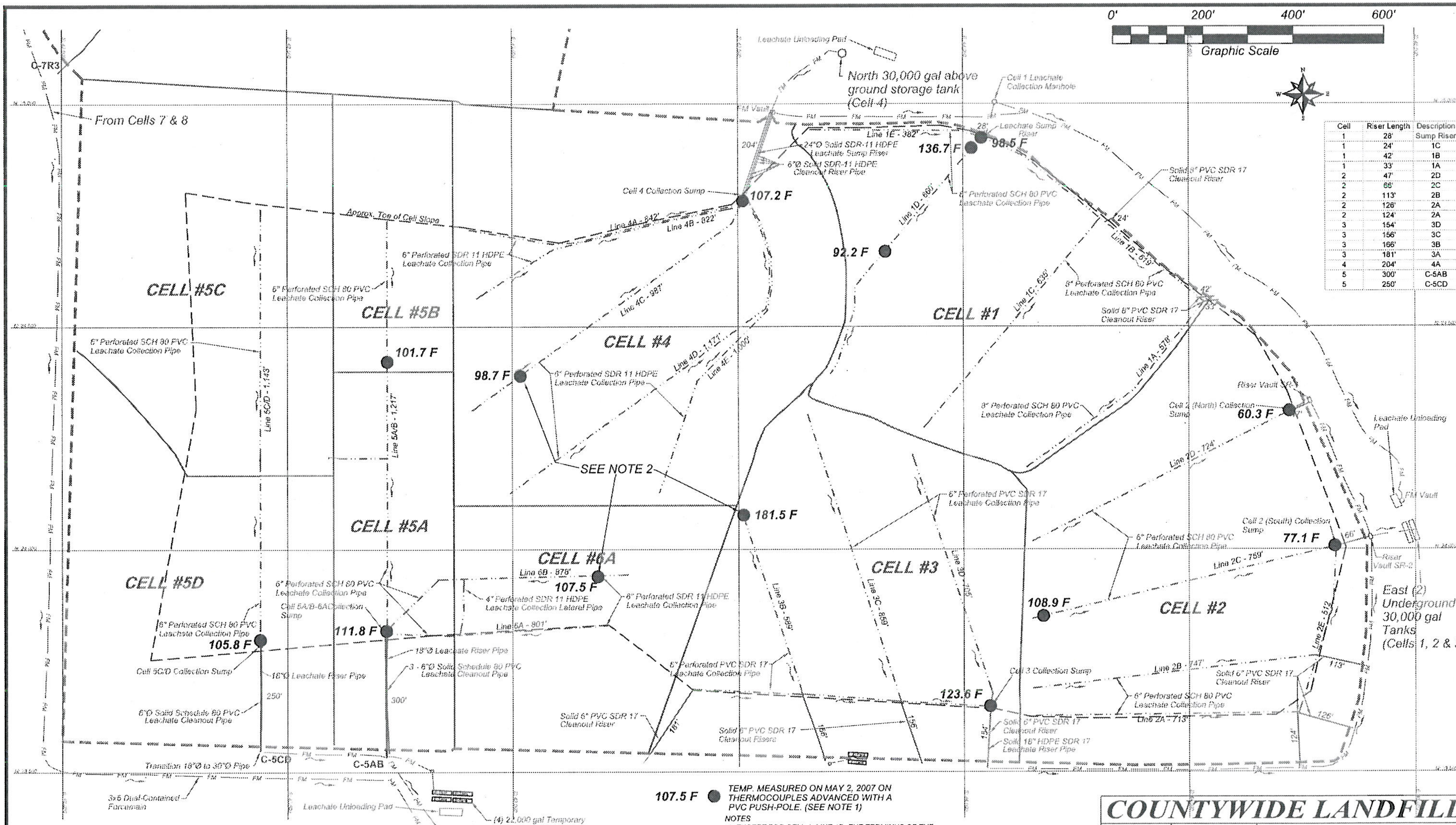
FIG. 4


WELL TEMPERATURE
COLOR LEGEND
Temp Zone(°F)
Greater Than 131
Greater Than 150
Greater Than 170
Greater Than 200
N
S
E
W
CELL #5C
CELL #5B
CELL #4
CELL #1
CELL #5A
CELL #5D
CELL #6A
CELL #3
CELL #2
Scale: 1 in. = 200 ft.
0'
200'
400'
600'
Graphic Scale
COUNTYWIDE LANDFILL
PROJECT:
ENGINEERED COMPONENT EVALUATION STUDY
SHEET TITLE:
APRIL 2007 WELLHEAD TEMPERATURES
EarthTech
FIG. 2



Cell	Riser Length	Description
		Sump Riser
1	28'	1C
1	24'	1B
1	42'	1B
1	33'	1A
2	47'	2D
2	66'	2C
2	113'	2B
2	126'	2A
2	124'	2A
3	154'	3D
3	156'	3C
3	166'	3B
3	181'	3A
4	204'	4A
5	300'	C-5AB
5	250'	C-5CD

107.5 F ● TEMP. MEASURED ON MAY 2, 2007 ON THERMOCOUPLES ADVANCED WITH A PVC PUSH-POLE. (SEE NOTE 1)

NOTES
1. EXCEPT FOR CELL 1, LINE 1D, THE TERMINUS OF THE ADVANCEMENT OF THE DEEP THERMOCOUPLES REPRESENTED THE HIGHEST TEMP.

2. THIS, AND OTHER DATA, WILL BE CHECKED USING A DIFFERENT STYLE THERMOCOUPLE TO REDUCE THE POTENTIAL FOR ELECTROMAGNETIC INTERFERNCE.

3. SEE TABLE 3 FOR DATA AND DISTANCES ADVANCED.

LEGEND NOTES:
1.) Leachate collection system features in Cells 1, 2, 3, 4, 5A, 5B, 5C, 5D & 6A were compiled from Bair, Goodie and Associates, Inc. "Leachate Management System" record drawings.

2.) Lengths shown for leachate collection pipes are slope corrected.

COUNTYWIDE LANDFILL

SCALE: 1" = 200' | REVISIONS

PROJECT: ENGINEERED COMPONENT EVALUATION STUDY

DRAWN: MRB 05-04-07
CHECKED: NKL 05-07-07
REVISED DATE:

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FIGURE TITLE: MAY 2007 THERMOCOUPLE STUDY

FIG. 6