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SCS ENGINEERS

March 17, 1994
File No. 0593034

RECEIVED

APR 05 1994

SWMP

POSTED

Mr. Frank J. Dolan, P.E.
Environmental Engineer
State of Missouri
Department of Natural Resources
Division of Environmental Quality
P.O. Box 176
Jefferson City, Missouri 65102-0176

Subject: Landfill Fire Mitigation, Westlakes Landfill, Permit 0118912 (Bridgeton Inc.)
St. Louis County, Missouri

Dear Mr. Dolan:

As you know, Laidlaw Waste Systems is currently proceeding with the investigation, design, and implementation of the landfill fire mitigation program at Westlakes Landfill. We earlier submitted a copy of our proposed approach to you, prepared by SCS Engineers, and dated December 10, 1993 (revised January 10, 1994). You forwarded comments to us on that proposal by your letter of March 8, 1994.

Item 1 of that letter requested submittal of three copies of the original document, stamped and sealed by a Registered Professional Engineer in the State of Missouri. That task has now been completed, and three copies are enclosed.

We will proceed to accommodate the remaining items in your March 8, 1994 letter. Three copies of the Tasks 4 and 5 reports (certified by a Registered Professional Engineer in the State of Missouri) will be forwarded to you as they become available.

Thank you for your consideration on this matter. If you have any questions or concerns, please do not hesitate to call me at the letterhead phone.

Sincerely,

James J. Walsh, P.E.
Project Director
SCS ENGINEERS

PROPOSAL

LANDFILL FIRE MITIGATION
LAIDLAW BRIDGETON SANITARY LANDFILL
BRIDGETON, MISSOURI

Submitted to:

Laidlaw Bridgeton Sanitary Landfill
Laidlaw Waste Systems, Inc.
13570 Saint Charles Rock Road
Bridgeton, Missouri 63044
(314) 739-1919

Submitted by:

SCS Engineers
2060 Reading Road
Cincinnati, Ohio 45202
(513) 421-5353

STATE OF MISSOURI
LARRY D. LOWRY
NUMBER
E21257
REGISTERED PROFESSIONAL ENGINEER
4/1/94

December 10, 1993
Revised January 10, 1994
File No. 0507893

PROPOSAL

LANDFILL FIRE MITIGATION
LAIDLAW BRIDGETON SANITARY LANDFILL
BRIDGETON, MISSOURI

BACKGROUND

This submittal represents a proposal from SCS Engineers for landfill fire mitigation at the Bridgeton Sanitary Landfill. Symptoms of landfill fire have existed at the Bridgeton Landfill for about one year. A fire appears to have developed in an area of the landfill indicated on Exhibit 1. The landfilling operation at Bridgeton consists of a quarry fill operation. As in all quarry fills, settlement of refuse mass creates a shear plane against the quarry sidewall. Typically, this shear plane develops into a separation distance of several inches. This separation gap provides the opportunity for air intrusion.

The Bridgeton Sanitary Landfill also has an active gas extraction system. This system consists of dozens of vertical gas extraction wells, and horizontal collectors. These all feed to an existing blower/flare station. At this location, the collected gases are combusted, and vented to atmosphere.

A horizontal collector formerly operated within several hundred feet of the fire area. Although the gas system is now closed off, this system may have created the opportunity for air intrusion into the gap between the landfill and its quarry sidewall. Specifically, the gas collection system places vacuum on subsurface refuse. The vacuum can be relieved through atmospheric intrusion, at the point of least resistance. This point of least resistance was likely the quarry sidewall, where a gap of several inches allowed easy entry of atmospheric air, to a depth of dozens of feet.

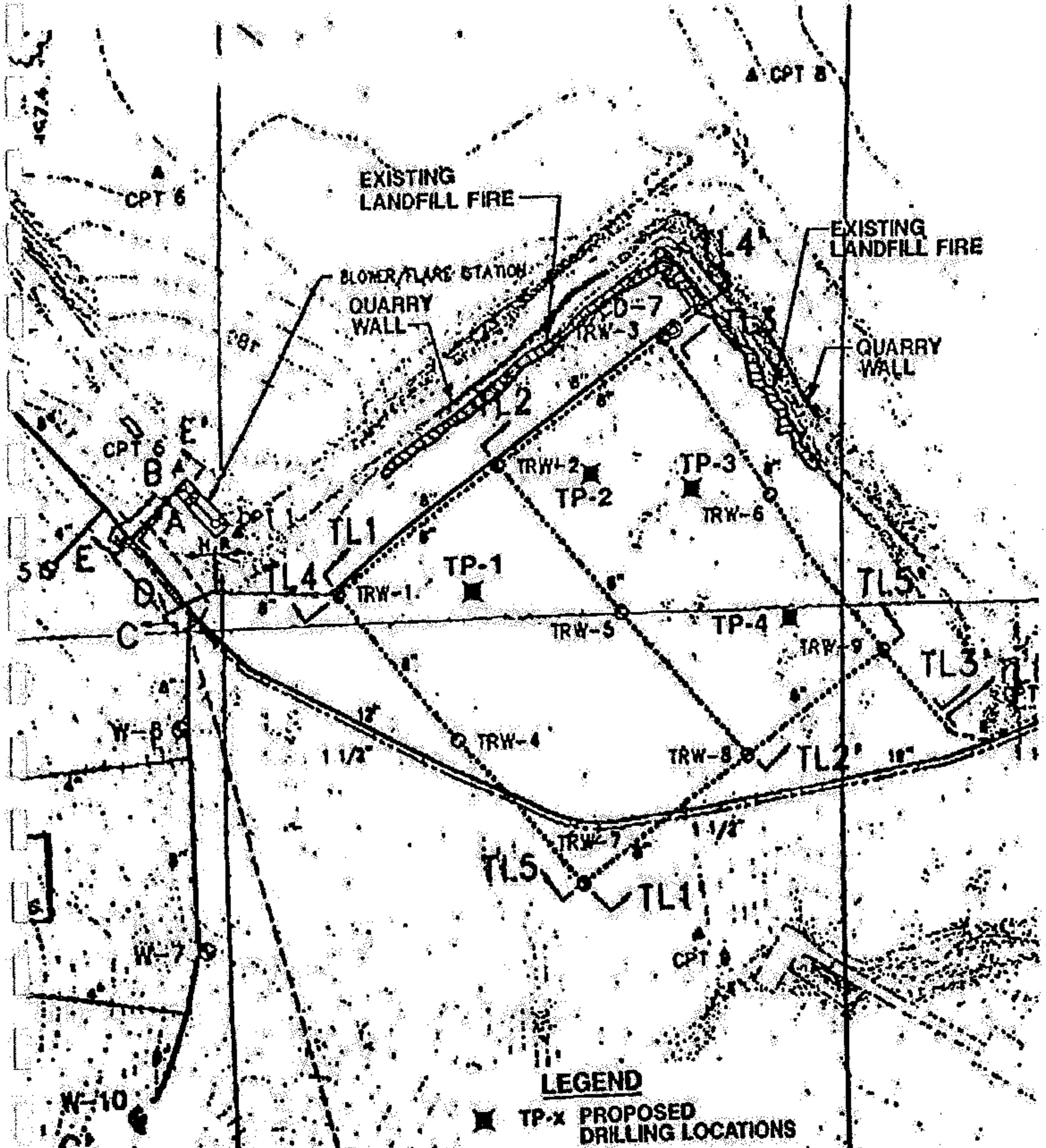
Since the time that fire symptoms were first detected, the gas extraction system has been turned off. In addition, the operators have piled cover soil atop the crack, in an effort to extinguish the fire and starve it from atmospheric air. Though this approach appears to have had some success, the fire continues in many areas to this date.

It is recognized at this point that piling additional cover soil atop the fire will likely not permanently mitigate the problem. As a result, this proposal was solicited. Its purpose was to develop an investigative program, to collected necessary background information, and determine the best mitigative approach to completely and permanently extinguish the landfill fire. As a final task under this proposal, mitigation would actually be applied.

The balance of this proposal addresses the proposed work scope, schedule, costs, project team, and qualifications for SCS Engineers. Our Scope of Work contains a total of five tasks. The first four of these tasks deal with investigation. The last of these assumes a certain mitigative approach, and proceeds to scope, schedule, and price that task.

EXHIBIT 1

PROPOSED TEMPERATURE PROBE LOCATIONS



SCOPE OF WORK

General

This portion of the proposal describes the approach to be taken in investigating and mitigating a potential landfill fire at the Laidlaw Bridgeton Landfill near St. Louis, Missouri. Based on its prior experience on other landfill fires, SCS has developed the following five tasks to accommodate the proposed work flow on this assignment.

- Task 1. Fly infrared thermography.
- Task 2. Install temperature probes.
- Task 3. Monitor temperature probes.
- Task 4. Prepare report and propose mitigation.
- Task 5. Mitigate landfill fire.

The balance of this section will identify the objectives and detailed approach to be taken under each of these tasks.

Task 1 -- Fly Infrared Thermography

Objectives--

1. Finalize plans for infrared thermography, including selection of appropriate technique and vendor.
2. Perform infrared thermography. Create color video tape and still photographs.
3. Process and evaluate thermography. Draw conclusions about subsurface fire, as a basis for temperature probe installation.

Approach--

SCS Engineers has utilized infrared thermography on other landfill fire projects. Those three projects, and the techniques applied at each are summarized below:

1. Port Washington Landfill, North Hempstead, New York

   Due to the improper operation of an existing landfill gas collection system, a subsurface fire apparently developed around selected gas extraction wells. To determine the depth, intensity, and extent of subsurface combustion, aerial thermography was flown at the Port Washington Landfill at the direction of SCS Engineers. The thermography was performed in about 1985, and prepared a single black and white photo taken from an airplane flown during night.

   The thermographic effort proved to be of little use. At this point, the more intense, surface manifestation of the fire had ceased to exist. In addition, the remaining fire appeared to be relatively calm, and at far greater depth. Little surface manifestation of the fire could be seen. This thermography proved to be valuable only in identifying that near-surface combustion was not occurring.

2. Industrial Excess Landfill, Uniontown, Ohio

Elevated carbon monoxide and subsurface temperature readings were recorded at this Superfund landfill. SCS was the design engineer of record, under contract to the U.S. EPA, and performing its Emergency Response Contract Services (ERCS) assignment. Based on prior experience by SCS on other sites, we recommended the performance of an aerial overflight to perform infrared thermography. Black and white videotape was prepared, using a plane flown during the night.

This was a relatively shallow landfill. The results and tape revealed little to no subsurface combustion. This was later confirmed with more intensive subsurface probing, including subsurface temperature profiles, well head monitoring, further carbon monoxide readings, and other related data.

In conclusion, the thermography at this site was useful in determining that the earlier feared landfill fire was now at a relatively low level, or altogether non-existent.

3. G B Auto Parts and Landfill, Ironton, Ohio

SCS Engineers responded to this landfill fire under its U.S. EPA Emergency Response Contract Services (ERCS) assignment. Approximately 5 acres of the total 10 acre site was actively burning. Smoke emanating from the landfill had caused the evacuation of several residential structures nearby.

In order to determine the subsurface extent of the fire (as it may be different from the surface manifestation), SCS ordered that an infrared photography be performed in 1993. An aerial plane overflight was performed during early evening hours after sunset. A color videotape was compiled, and used for subsequent interpretation.

The actively burning areas (as could be seen from the ground surface) were confirmed through the infrared thermogram as having active combustion. Active combustion appeared to be confined to these areas of surface manifestation. Because the landfill was relatively shallow (30 ft or less) and in combination with infrared photography, it was determined that the fire was confined to those areas emanating smoke. The infrared thermography was therefore useful in determining that the subsurface fire was not more extensive than what could be seen on the surface.

Based on the above, SCS has had mixed results with the use of infrared thermography in the past. In some cases, it has been successful in determining the extent of subsurface combustion, as it may exceed those areas readily identified through surface manifestation of smoke. In other cases, the buffering effects of soil could mislead interpretation of the aerial overflight. This is a particular problem if the combustion is contained at great depth, as often occurs in deeper landfills.

Generally, there exist several alternatives for performance of infrared thermograms:

1. Black and white versus color.
2. Videotape versus still photos.
3. Ground surface examination versus aerial overflight.
4. Helicopter versus airplane.

Based on our prior experience, we recommend that Laidlaw proceed with infrared thermography at this site. Although there is some risk that the thermogram could be misleading or fail to add new information, on balance we find it to be a useful tool. Our chief purpose here would be to determine whether subsurface combustion has spread laterally, at shallow distance, beyond those areas currently emanating smoke. If so, placement of temperature probes in these areas would be appropriate. Thus, the outcome of Task 1 (Thermography) could readily affect Task 2 (Temperature Probe Installation).

At this time, we recommend use of a helicopter, to compile color videotape atop the site. This should be flown during nighttime, with early morning hours preferred. The videotape can be used for subsequent interpretation. From past experience, the color videotape can be used to prepare still photographs, produced at the same scale as topographic maps. In this manner, the exact limits of the subsurface combustion can be drawn to scale, on topographic maps available from other sources.

As a first step as work proceeds, SCS would research available contractors capable of performing infrared thermography in the St. Louis area. SCS has utilized Midwest Aerial Photography out of Columbus, Ohio for this purpose. Another candidate is Entech Systems from St. Louis. The expected cost of this effort would be approximately $4,000. The deliverable would include a color videotape, and a select number of still photos.

After contacting these and other aerial firms, a determination would be made as to price, technology, approach, quality, and delivery schedule. A final selection would then be made. Plans would be prepared for the aerial overflight itself. The overflight would then be performed at night with SCS personnel present.

The videotape from the overflight is expected to be available immediately. It would be viewed and interpreted with "ground truthing" performed, to identify the fringe areas of fire. Selected images within the videotape would be identified, and compiled into still photographs. These still photos would be prepared to scale. The two scaled photographs would then be utilized to draw the extent of the fire on the topographic maps described above.

As an outcome of this task, a determination can be made as to the placement of the temperature probes under Task 2. A plan for their placement is already included here in this proposal. However, modification of their location, or expansion of the number of probes, may be both be necessary as a result of the infrared photography here.

Task 2 -- Install Temperature Probes

Objectives--

1. Finalize plan for installation of temperature probes including location, installation, and backfill. The final plan to be based upon results of Task 1 infrared thermography.

2. Contact competent drilling firm for well installations. Capability must include angled drilling proposed for this program. Select a driller based on availability, capability, quality, delivery schedule, and price.

3. Install two drilled-well clusters at two separate locations in the landfill. These locations to be generally offset from the quarry edge by about 50 ft back from the existing fire area.

4. Each cluster to consist of two separate well points. One to be vertical, and 75 ft deep. The other to be angled, and traverse through the quarry wall.

5. Supervise well drilling and backfill operations. Compile boring logs. Make on-site design decisions. Complete backfill and well construction.

Approach--

Another useful tool in examining subsurface landfill fires, is the installation of dedicated temperature monitoring points. SCS Engineers has installed such points at numerous landfills. Typically, they are installed with steel or iron pipe. Through use of down hole thermocouples, we can determine the temperature levels and gradient, at two ft differentials down the entire bore hole depth. This allows us to determine the presence, intensity, and depth of any landfill fire.

At this time, and based on expected results from Task 1, we anticipate installing two separate well clusters. Each cluster would have two wells, one of them vertically downward, and one of them angled toward the quarry wall. The straight vertical wells are an estimated 75 ft deep from the ground surface. The angled wells are an estimated 80 ft deep. Both wells would be installed in the same general location, offset into the landfill about 50 ft from the quarry wall. The vertical well would be installed first, followed by the angled well. Our intention is to install the angled well through the quarry wall by several feet, and to determine the presence of combustion at this interface.

Boring logs would be carefully compiled during well installations. Any refuse removed from the bore hole would be examined for elevated temperature. Temperatures would be recorded, and other physical observations made on the boring logs.

Steel or iron pipe, 1 in. in diameter, would be installed to the bottom of each of these eight bore holes. Proposed bore hole locations are as indicated on Exhibit 1. All holes would then be backfilled with gravel around the perforated interval (estimated to begin 5 ft below the ground surface). The annular space within 5 ft of the surface would be packed with clay and concrete material, to provide structural and airtight integrity.

Task 3 -- Monitor Temperature Probes

Objectives--

1. Perform down hole temperature and other monitoring of all four monitoring probes. Perform monitoring twice, at two week intervals.

2. Perform monitoring for down-hole temperature, gas composition, water presence, and trace constituents.

3. Record selected "ambient landfill temperatures" at gas extraction wells located elsewhere on the fill. Utilize this data as a baseline.

Approach--

The primary purpose of the temperature monitoring probes would be to collect data on down hole temperatures at various intervals. SCS has in its possession several down-hole thermocouples. These have been used in the past to record landfill temperatures, at periodic intervals, down the total well depth.

Steel or iron well points have been installed to fend against attack from any subsurface landfill combustion. Plastic well points (though less expensive) would melt or otherwise fail as a result of the elevated temperatures found in a landfill fire. Steel well points are more durable, and have shown to sustain around landfill fire.

SCS proposes to perform two separate rounds of temperature monitoring associated with these eight well points. Monitoring would be performed at two week intervals for a total of two rounds, over a two week term. SCS would perform the first monitoring, immediately after the time of well installation and backfill. Simultaneously, SCS would train Laidlaw personnel, and leave monitoring equipment. This would allow Laidlaw to lead monitoring round two, two weeks after original well installation.

During each monitoring round, and at each of the four well points, the following monitoring would be performed:

1. Most importantly, down-hole temperatures in degrees F, at two ft intervals down each probe. Down-hole temperature monitoring allows one to see a gradient of subsurface temperatures. The location, intensity, and depth of any subsurface combustion can be determined.

2. Well head pressure.

3. Gas composition including methane, oxygen, and carbon dioxide. These major constituents would be monitored using handheld instruments available at SCS.

4. Water level.

5. Total well depth.

6. Trace constituents including carbon monoxide (CO) and vinyl chloride (VC). These parameters would be monitored using either Draeger tubes or handheld instruments.

SCS will also collect selected ambient temperature data on other gas extraction wells located at Bridgeton Landfill. From past experience, we find that temperatures that may otherwise indicate a landfill fire, can sometimes be an indication of "elevated anaerobic decomposition". To determine this condition, down hole temperatures should be recorded from at least three other ambient landfill gas extraction wells, located in other portions of the landfill, where they are apparently unaffected by potential fire. This data can then serve as a baseline, to allow comparison with down hole temperatures from the ~~eight~~ four selected wells in our temperature well clusters.

<u>Task 4 -- Prepare Report and Propose Mitigation</u>

Objectives--

1. Tabulate and plot temperature and other monitoring data.

2. Determine temperature trends at each well location. Compare with background conditions. Determine presence, extent, depth, and intensity of any subsurface fire.

3. Utilize infrared photography to determine presence of any likely fire.

4. Compile and evaluate background data on existing gas collection system. Determine and evaluate history of "landfill fire" as told by Laidlaw operations personnel.

5. Draw final conclusions on subsurface fire.

6. Prepare recommendations on need for and approach taken by, mitigation.

Approach--

Following the second temperature monitoring round, all data will be tabulated, plotted, and evaluated. The infrared thermogram would also be used to evaluate data, with the new temperature data in hand. Historical perspective on the landfill fire will be gained, by interviewing Laidlaw personnel. Lastly, the configuration of the existing landfill gas extraction system will be examined. This system could have an impact on starting or promoting any landfill fire.

After examination of this data, SCS will be able to determine the following factors:

1. Is a landfill fire present? Where is it located, at what intensity, and at what depth?

2. How did the landfill fire likely begin? Is it now expanding? What are the future risks of "no action"?

3. Should mitigative steps be taken? If so, what technique should be applied? What is the specific approach, schedule, and cost?

At the conclusion of this Task, SCS will submit a report on the subject. This report will include the following contents:

1. Introduction and background.

2. Compilation of existing data.

3. Compilation of new data from test monitoring program.

4. Discussion, evaluation, and conclusions.

5. Recommendation on landfill fire mitigation.

The report will be submitted in draft form to Laidlaw personnel for review. A meeting will be conducted to present our findings. Based on comments received, the report will be finalized, and final recommendations on mitigative action will be made.

<u>Task 5 -- Mitigate Landfill Fire</u>

Objectives--

1. Implement approach chosen during Task 4 report. Mobilize equipment to site. Set up for landfill fire mitigation.

2. Apply methodology for landfill fire mitigation in a first application. Monitor thereafter, to determine effectiveness.

3. Perform second and third applications if needed. Continue to monitor to determine effectiveness.

4. After halting mitigative action, continue to monitor periodically thereafter, to ascertain continued effectiveness.

5. Prepare final letter report to Laidlaw, reporting on mitigative action, its success, and its prospects for maintenance in the future.

Approach--

SCS Engineers has been involved in numerous landfill fire investigations and mitigations in the past. Some of the tools typically used in identifying and researching landfill fires have included those previously mentioned: infrared thermography, down-hole temperature monitoring, etc. Based on these prior efforts, we have proposed mitigative actions. The actions applied previously, which may have some relevance here, include:

1. Gas system.

Often a landfill fire is related to an existing gas extraction system. If overdrawn, or if channels for rapid air intrusion are created, there exists the potential for gas extraction systems to draw in atmospheric air, starting or fueling an existing landfill fire.

From past experience, the gas extraction system in the suspected area must immediately be turned off. The fire must be proven to be totally extinguished, before the gas system can be returned to operation.

The first step has already been taken at Bridgeton Landfill, with deactivation of the gas extraction system in the area of the alleged landfill fire. Monitoring can be performed during Task 3 of this program, to ascertain whether a zone of influence effect no longer exists in this area.

2. Soil cover.

Once a landfill fire begins, it can "breathe in" its own oxygen from the atmosphere, to a greater depth than may otherwise occur in a common anaerobically-decomposing sanitary landfill. Even with halting the operation of a gas extraction system, our experience indicates that landfill fires 10 or 20 ft deep (or deeper) can reach to the landfill surface, and draw in oxygen. Commonly, SCS moves to apply additional clay soil cover. The effect of this cover will be to starve or shut off such air intrusion.

To this end, SCS has applied 4 ft of compacted clay soil to the G B Auto Parts and Landfill in Ironton, Ohio. This approach appears to be successful in starving the existing landfill fire, and lowering temperatures. With time, we expect the fire will be totally extinguished. Unfortunately, some level of subsurface combustion will likely occur for many months to come.

3. Foam application.

Chemical foams are commonly used by fire fighting departments, and have been used for landfill fires in the past. They are particularly effective when the fire manifests itself on the surface of the landfill. Clearly this is not the case at Bridgeton Landfill. Though foams have some effectiveness subsurface, particularly when injected below grade, they do not long survive. Most foam lasts for less than a day, unless special agents are added. Even when such agents are added, longevity for no more than two weeks can be expected.

Foam provides the following beneficial effects: adds water to cool and extinguish the fire, minimizes or prevents air intrusion, and otherwise covers or suffocates such combustion. However, the longevity of such foam makes it questionable for subsurface fire mitigation.

4. Liquid nitrogen or carbon dioxide.

SCS has applied liquid nitrogen and carbon dioxide on three sites to date. Typically, the material is injected through the temperature monitoring probes (described under Task 2) to the subsurface fire area. As for foam above, liquid gases have the following benefits: cools the fire, extinguishes the fire, and prevents air/oxygen intrusion. However, like foams, liquid nitrogen and carbon dioxide can be very expensive. Our past experience indicates that the materials applied escape rapidly to atmosphere. New material must be constantly applied over a multi-week period.

5. Water application.

Water application may have some relevance on landfill fires. Obviously they provide all the benefits of foams or liquid nitrogen and carbon dioxide. They cool, smother, and seal off from air intrusion. However, they also add water to a landfill, which is usually undesirable, since the application of water can create additional leachate quantities. Without a well sealed bottom-lined landfill, water application is not advised.

6. Bentonite slurry application.

A slurry or bentonite application lasts longer than foam or liquid air injections. Like foams, slurries also provide the benefits of cooling, fire extinguishment, and air sealing. SCS has used such applications in any of the following scenarios: (1) flooding a given ground surface area with bentonite soil, so as to minimize air intrusion; (2) subsurface injection through temperature monitoring probes or other ports; and (3) injection into landfill cracks.

The latter seems like the best choice at Bridgeton Landfill, owing to the large crack along the interface of the quarry wall and refuse fill.

At this time it appears the bentonite slurry application may have most value. Thus, the chronology of assumed actions we present here is based upon selection of slurry as the preferred application.

As a first step, equipment for bentonite slurry material would be mobilized to the site. The slurry would be mixed, and pumped into the crack along the quarry sidewall. Thereafter, temperature probes would be monitored, in an effort to determine whether the slurry has had any benefit.

Some settlement of the slurry can be expected over a period of several days. As a result, and for scoping purposes, we propose that the slurry application equipment remain on site, and be used for a second application some two weeks later. Again temperature probes will be monitored. Some settlement would likely occur. Finally, a third application would occur two weeks later.

Monitoring would be performed thereafter. Based on past experience, it is assumed that the fire would be adequately settled at this point, to allow for the slurry equipment to de-mobilized from the site.

From past experience, some subsurface combustion can be expected for months thereafter. However, the temperatures should gradually decrease over time. Surface manifestation of fire should not occur. Subsurface temperature monitoring should continue, in an effort to determine that the levels have returned to acceptable ranges, and that the trend continues downward. This monitoring would be performed by Laidlaw personnel, based on guidance provided by SCS.

PROJECT SCHEDULE

The proposed project schedule for this program has been included as Exhibit 2. As shown, the total investigative program would be completed within 2½ months after project initiation. This includes two to four weeks for aerial thermography, two to three weeks for temperature probe installation, four weeks for temperature probe monitoring, and four weeks for report preparation and agreement on the proposed mitigation. Several of these tasks overlap, creating a total estimated 2½ month period of performance.

Mitigation of the landfill fire can proceed thereafter. A significant portion of this work would be performed within four weeks of initiation of this task. For budgeting purposes, SCS effort would expire at the end of that six month term (based on the mitigation now proposed). Some involvement by Laidlaw personnel to continue monitoring the situation for several months thereafter would likely be required.

PROJECT COSTS

Vendor costs on this program include those for a driller and for performance of the aerial thermogram. Drilling and probe installation costs have been estimated in Exhibit 3, and amount to $5,401. The aerial thermogram has been estimated at $4,000. This is predicated on the performance of a single aerial overflight using a helicopter, and compilation of a color videotape to observe subsurface thermographic conditions. Processing of selected still photographs from the videotape has also been included within this amount.

SCS manhours and total costs have been presented by task in Exhibit 4. A summary of those costs has been included on Exhibit 5. Please note that these costs are negotiable. Outside vendor costs can be contracted directly to Laidlaw Waste Systems if appropriate. In addition, Laidlaw could choose to initiate and proceed with any individual task, foregoing application of subsequent tasks until the outcome of early tasks has become known.

The specifics surrounding our proposed costs for Task 5 are detailed below:

1. We have provided a budgetary estimate of $10,000 for the additional construction-related activity under Task 5, Landfill Fire Mitigation. This includes a total of five days of on-site activity, at an estimated $2,000 per day.

2. Our original proposal described the application of a slurry grout injection along the landfill sidewall during each of three separate rounds. The first round was to be the most expansive, and was to consume a total of three elapsed days. The subsequent two rounds were to be at two week intervals thereafter. Each round

EXHIBIT 2

PROJECT SCHEDULE

Task No. and Title	Months from Project Start				
	1	2	3	4	5
1. Fly Infrared Thermography	--------				
2. Install Temperature Probes	-----	--			
3. Monitor Temperature Probes		--------			
4. Prepare Report and Propose Mitigation		-----	---		
5. Mitigate Landfill Fire				--------	---->

<u>Activity:</u>

-------- SCS Activity

EXHIBIT 2

PROJECT SCHEDULE

Task No. and Title	Months from Project Start				
	1	2	3	4	5
1. Fly Infrared Thermography	--------				
2. Install Temperature Probes	-----	--			
3. Monitor Temperature Probes		--------			
4. Prepare Report and Propose Mitigation		----	---		
5. Mitigate Landfill Fire				--------	---->

<u>Activity:</u>

-------- SCS Activity

EXHIBIT 3

DRILLING/PROBE INSTALLATION COST ESTIMATE

1.	Mobilization		$100
2.	Drilling		
	-- 2 straight holes x 75 ft deep each	= 150 ft x $9/ft	1,350
	-- 2 angled holes x 80 ft deep each	= 160 ft x $11/ft	1,760
3.	Probe Installation		
	-- 2 straight holes	= 150 ft x $5/ft	750
	-- 2 angled holes	= 150 ft x $5/ft	750
4.	Decontamination Charge		200
Subtotal			$4,910
5.	Contingency (10%)		491
TOTAL			$5,401

EXHIBIT 4

DETAILED COST ESTIMATE

Labor Classification	Rates	Task 1 Infra-Red Thermography	Task 2 Install Probes	Task 3 Monitor Probes	Task 4 Report	Task 5 Mitigate*	Total
LABOR MAN-HOURS:							
Project Director		4	4	4	8	16	36
Sr. Project Engineer		16	8	8	16	64	112
Staff Engineer		8	32	16	16	80	152
Drafter		--	4	--	8	8	20
Secretary		4	4	--	16	16	40
Subtotal -- Labor Man-Hours		32	52	28	64	184	360
LABOR DOLLARS:							
Project Director	$135 /hr	$540	$540	$540	$1,080	$2,160	$4,860
Sr. Project Engineer	89 /hr	1,424	712	712	1,424	5,696	9,968
Staff Engineer	56 /hr	448	1,792	896	896	4,480	8,512
Drafter	42 /hr	--	168	--	336	336	840
Secretary	38 /hr	152	152	--	608	608	1,520
Subtotal -- Labor Dollars		$2,564	$3,364	$2,148	$4,344	$13,280	$25,700
EXPENSES:							
Thermography		$4,000	--	--	--	--	$4,000
Drilling/Probe Installation		--	5,401	--	--	--	5,401
Grout Slurry Contract Cost		--	--	--	--	10,000	10,000
Travel		1,000	1,000	1,000	500	1,500	5,000
Per Diem	$75 /day	225	375	225	150	600	1,575
Field Equipment		100	200	200	--	200	700
Supplies		100	200	100	--	200	600
Reproduction		50	50	50	100	50	300
Express/Shipping		50	50	50	100	100	350
Computer	$30 /hr	150	240	--	480	150	1,020
Long-Distance Telephone		25	50	25	50	75	225
G&A (15% of outside non-labor expenses)		810	1,061	210	120	1,871	4,073
Subtotal -- Expenses		$6,510	$8,627	$1,860	$1,500	$14,746	$33,244
TOTAL		$9,074	$11,991	$4,008	$5,844	$28,026	$58,944

* Note: Task 5 costs estimated, and dependent upon mitigation selected and the duration of its application. Task 5 includes SCS costs, but excludes any outside cost for mitigation materials, supplies, or equipment.

EXHIBIT 5

COST SUMMARY

Task No. and Title	SCS Labor And Expenses	Outside Venders
1. Fly Infrared Thermography	$5,074	$4,000
2. Install Temperature Probes	6,590	5,401
3. Monitor Temperature Probes	4,008	--
4. Prepare Report and Propose Mitigation	5,844	--
5. Mitigate Landfill Fire	18,026	10,000
TOTAL	$39,542	$19,401

was estimated to consume a total of one day. Thus, among all three rounds, a total of five days would be consumed.

3. In calculating our unit daily cost, we have assumed that heavy equipment would be provided through this contract to cut a bench in the existing mound of soil piled atop the landfill fire. This would be applied only in the first round. The bulldozer would be demobilized after the first round, and not used thereafter.

   For the first and subsequent two rounds, a cement mixer, conveyor, bentonite, water, and an estimated two to four personnel would be required each day. Some nominal support may be required from on-site Laidlaw personnel and operating equipment. However, this assistance would be on a spot basis, and would not be required full-time during those days.

SCS PROJECT TEAM

Three key personnel have been assigned to performance of this Laidlaw project. These include James Walsh (as Project Director), William Held (as Senior Project Engineer), and Eric Waldmann (as Staff Engineer). Qualifications of each of these individuals with regard to landfill fires is summarized below.

James J. Walsh, P.E. has a B.S. in Civil Engineering, and is a registered professional engineer in multiple states. Mr. Walsh has nearly 20 years professional experience in landfill and landfill gas projects. To date, he has been engaged on four separate landfill fires. Landfill fire projects have included Industrial Excess Landfill in Uniontown, Ohio; Port Washington Landfill in North Hempstead, New York; Lake County Landfill in Cleveland, Ohio; and G B Auto Parts and Landfill in Ironton, Ohio. Through these projects, Mr. Walsh has gained successful experience with various landfill fire investigative and mitigative approaches. Investigative approaches have included temperature probe installation and aerial thermograms. Mitigative approaches successfully applied have included: liquid nitrogen injection, liquid carbon dioxide injection, and clay cap application.

William M. Held is a degreed civil and environmental engineer. Mr. Held has 13 years professional experience, mostly on landfill and landfill gas projects. He has performed past work at the Bridgeton Landfill on behalf of Laidlaw Waste Systems. He has used the investigative measures and mitigation actions proposed for this project including: temperature probe installations, subsurface temperature profiles, aerial overflights, well head gas monitoring, and clay cover application.

Eric J. Waldmann is a design engineer with five years professional experience. Since joining SCS, Mr. Waldmann has been engaged nearly full-time on landfill and landfill gas projects. Most recently, he has been engaged on a full-time basis over a multi-month period at the GB Auto Parts and Landfill in Ironton, Ohio. At this site, he was responsible for landfill fire mitigation. Investigative actions supervised by Mr. Waldmann included temperature probe installation, subsurface temperature profiles, aerial overflight, thermogram, and clay cover application.

EXHIBIT 6

REPRESENTATIVE LANDFILL FIRE AND EXCAVATION PROJECTS

- Subsurface Fire Investigation at NPL Landfill Site, Industrial Excess Landfill, Uniontown, Ohio.
- Subsurface Fire Investigation, Extinguishment and Post-Extinguishment Monitoring, Lake County Landfill, Cleveland, Ohio.
- Subsurface Landfill Fire Control and Extinguishment via Carbon Dioxide Injection, South Bay Six Drive-In Theater, Carson, California.
- Landfill Fire Control Utilizing Subsurface Flooding, Excavation and Addition of Suitable Cover Material at Five Adjacent Landfill Sites, Wilmington, California.
- Repair of Fire Damaged LFG Recovery Facilities/Regrading of Settled Areas, Wilmington, California.
- Identification and Monitoring of Subsurface Landfill Fire Impacting LFG Migration Control Facilities, Mountaingate Development, Los Angeles, California.
- Identification and Control Plan Development for Subsurface Landfill Fire, Industry Hills Development, Industry Hills, California.
- Development of Landfill Fire Mitigation Program, Industry Hills Development, Industry Hills, California.
- Development of Landfill Fire Control Program, Guam.
- Landfill Fire Status Evaluation and Development of Short-Term Mitigation Plan, Including Health and Safety Risk Assessment, Go East Landfill, Snohomish County, Washington.
- Subsurface Landfill Fire Control and Extinguishment, Palailai Sanitary Landfill, Oahu, Hawaii.
- Subsurface Landfill Fire Control and Extinguishment, Laguna Seca Landfill, Monterey County, California.
- Subsurface Landfill Fire Investigation and Control, Mountain View Sanitary Landfill, Mountain View, California.
- Subsurface Landfill Combustion Investigation, Port Washington Landfill, Town of North Hempstead, New York.
- Landfill Fire Consulting, Salem, New Hampshire.
- Subsurface Landfill Fire, Preliminary Investigation, Ferry Point Park, New York City, New York.
- Landfill Excavation, Denton Avenue, Developed Health and Safety Plan and Monitored Compliance, Town of North Hempstead, New York.
- Landfill Relocation, Construction Contract Documents, and Health and Safety, Avondale Landfill, Arizona. 700,000 cubic yards of refuse was relocated from an old landfill in a floodplain to a new, lined site.

SCS QUALIFICATIONS

SCS Engineers is an environmental engineering consulting firm, specializing in solid waste management. The firm has ten engineering offices located throughout the nation. Out of approximately $35 million in annual consulting fees, approximately one-half of that work deals with landfill engineering. Practice areas include landfill gas control, landfill gas recovery, landfill engineering, permitting, site selection, hydrogeologic investigations, geotechnical investigations, construction quality assurance, and landfill fires.

The appendix to this proposal includes brochures of SCS Engineers, describing our general background. In addition, the firm has detailed experience on landfill fires. Principals of the firm have authored previous articles on the subject of landfill fires. A complete listing of landfill fire projects has been included as Exhibit 6. Selected key of those projects are highlighted below, as a demonstration of our landfill fire experience.

1. Lake County Landfill, Cleveland, Ohio

   A localized landfill fire had developed at this active landfill, as a result of failure of an interface between an active landfill gas withdrawal well, and the geomembrane cap. Extensive quantities of atmospheric air were drawn in, starting or fueling the fire. The fire rapidly expanded to cover an area about 1 acre in size, with a depth exceeding 40 ft.

   Initially, steps were taken by the operator to dig out the refuse. The fire depth was found to be greater than that which could be readily handled by the landfill operator. As a result, the landfill fire was re-sealed. SCS was subsequently mobilized to the site.

   SCS recommended installation of steel point monitoring wells, to determine the subsurface temperature profile. Monitoring was performed over a two week period. The exact location and intensity of the fire was determined. These same steel well points were later used for injection of liquid carbon dioxide and nitrogen. This had the effect of lowering landfill temperatures, and eventually extinguished the fire.

   Temperature monitoring was performed thereafter for a multi-month period. At the end of a one year term, temperatures had returned to ambient conditions found elsewhere throughout the site. As a result of these efforts, the landfill could then be successfully closed.

2. G B Auto Parts and Landfill, Ironton, Ohio

   SCS Engineers responded under its U.S. EPA contract for Emergency Response Contract Services (ERCS). An approximately 5 acre area of the landfill was burning at the time SCS arrived at the site. The immediate concern was with residential structures located near the site. As a result of the smoke, approximately 10 such structures were evacuated, until the hazard could be removed.

SCS supervised the installation of temperature monitoring points, to determine the depth of the landfill fire. In addition, an aerial thermogram was performed. This revealed the subsurface fire was limited to those areas now burning at the surface.

SCS then recommended the application of a two ft thick clay cap. Within three days the smoke had disappeared from the site. Subsequent temperature monitoring revealed that the fire remained, albeit at controlled depths. A thicker clay cap was then applied, and a program of long-term temperature monitoring was implemented.

The fire has now been extinguished for an approximate one month term. It is expected that temperature monitoring will continue for a one year period. At the end of that time, it is expected that subsurface temperatures will have returned to ambient conditions.

3. South Bay Six Drive-In Theater, Carson, California

This was a former quarry pit utilized as a sanitary landfill. Refuse had been filled approximately 150 ft deep, to the top of the quarry. Upon landfill completion, the final surface was used as a drive-in theater. A landfill gas extraction system was installed throughout the site, to protect theater occupants.

The operator of the gas collection system failed to prevent air intrusion. As a result, a subsurface fire started, and expanded over several acres. In addition, the fire extended to great depth. Subsequent temperature monitoring revealed that the landfill fire extended to depths exceeding 100 ft.

SCS mobilized to the site, and installed several steel monitoring points. These points were used for temperature monitoring, and subsequently for a liquid gas injection (nitrogen and carbon dioxide). These injections had success in extinguishing the landfill fire. In the months thereafter, temperatures slowly returned to ambient conditions.

In all, SCS has been involved in approximately 18 landfill fire related projects. Those projects are listed on Exhibit 6. In addition, we invite you to review the articles included in the appendix of this report.

APPENDIX A

LANDFILL FIRE ARTICLES BY SCS ENGINEERS

Treating Subsurface Landfill Fires

The days of hoping a fire within a landfill would "burn itself out" are gone. Today's landfill operator seeks to find troublespots early, and has several options for treatment.

by Robert C. Stearns and Galen S. Petoyan

Years ago, open burning dumps served as our solid waste disposal sites. Wastes were purposely burned with attendant smoke emissions and waste volume reduction. Burning was slow and often incomplete. Many former burning dumps smoldered for years following their closure.

With the advent of sanitary landfills, open burning ceased and our solid wastes were compacted and buried with layers of soil. As a result, open burning was replaced with the relatively slow biological decomposition of the waste materials with landfill gas (LFG) production. LFG was soon recognized as both a safety hazard and as an energy recovery opportunity.

The potential impacts of landfill settlement on LFG recovery/control system design and operation have been recognized. However, little information has been available on subsurface landfill fires. As efforts are made to increase LFG recovery, or to control LFG emissions or migration, subsurface fire problems can be expected to increase.

Fire mechanics

Ignition and propagation of subsurface landfill fires is complex and a function of many factors. These include waste composition and moisture content, available oxygen, ambient pressure in area of combustion, etc.

In general, as a combustible material is heated, either through biological decomposition or chemical oxidation, ignition will occur at some given temperature, termed the ignition temperature for the material. The resulting heat of combustion will support flame spread under most conditions. Combustion will continue until at least one of the following occurs:

- The combustible material is consumed
- The oxidizing agent (typically atmospheric oxygen) is depleted
- Heat acting as the ignition source is removed faster than it is produced.

> Identification and size determination for a subsurface fire can be difficult. A subsurface fire is typically indicated by:
>
> - unusual or rapid settlement;
> - venting of smoke;
> - carbon monoxide in extracted LFG;
> - combustion residue in header lines; and
> - elevated LFG temperatures.
>
> Determination of the location and a real extent of the subsurface fire can involve several approaches. These are:
>
> - thermographic scans;
> - excavation or borings to allow visual examination of refuse; and
> - installation of test wells to allow monitoring of subsurface temperature gradients.

Organic waste materials (containing primarily carbon and hydrogen) buried in a landfill decompose aerobically (in the presence of oxygen) or anaerobically (in the absence of oxygen), and release heat in the process. For most materials, the rate of biological decomposition is slow. Produced heat is transferred to surroundings as it is formed, and a stable, but somewhat elevated, temperature occurs as decomposition proceeds.

Spontaneous ignition (autoignition) of a combustible material can occur if enough air is available and higher temperatures exist to permit chemical oxidation. Under highly insulating conditions, the heat produced is retained and the chemical oxidation rate continues to increase. Under these conditions, the combustible material will eventually reach its ignition temperature and spontaneous combustion will occur. The rate of heat generation, available air supply, and the insulating properties of the surrounding materials all influence whether chemical oxidation will result in temperatures reaching and/or exceeding ignition temperatures of the combustible material.

Wastes placed in a landfill initially undergo biological decomposition aerobically, producing carbon dioxide (CO_2), water, and heat which can result in maximum landfill temperatures in the 140° to 160° Fahrenheit range. As available oxygen is consumed (assuming a new source of oxygen is not available), biological decomposition becomes anaerobic with resultant production of

Subsurface Landfill Fire Control Technique Selection

Fire Control Technique	APPLICABILITY					
	Fire Depth		Extraction System		On-Site Development	
	<30'	>30'	Control	Recovery	Vacant	Developed*
Excavation	Yes	No	Yes	Yes	Yes	No
Smother	Yes	No	Yes	Yes	Yes	Yes
Extinguish						
Inject inert gas	Yes	Yes	Yes	Yes	Yes	Yes
Inject water	Yes	Yes	No	Yes	Yes	Yes

*Site surface developed as golf course, drive-in theater, storage facility, etc., requiring public site occupancy.

methane (CH_4) and CO_2. Heat is also a product of anaerobic decomposition. Temperatures will remain in the 140° to 160° F range if the insulating properties of the waste materials are high. In loosely compacted or dry landfills, the heat retention is inadequate, and temperatures usually return to the 70° to 110° F range.

The high insulating characteristics of in-place refuse causes retention of heat within the refuse mass. Increasing temperatures cause an increase in the rate of chemical oxidation of refuse (which initially occurs simultaneously with biological decomposition processes). This heating can continue past the limit of biological survival of the bacteria. Heating to the point of spontaneous combustion is the result of continued chemical oxidation, which follows the initial heat generated by biological decomposition. A continuous source of oxygen is necessary for this process to proceed to the point of ignition.

As temperatures within the landfill increase, the refuse material undergoes pyrolysis, i.e., chemical decomposition of matter through the action of heat. Pyrolysis converts the refuse material to a black carbonaceous char. Continued air supply bringing additional oxygen in contact with the pyrolyzing refuse causes the char material to become red hot. The heat generated is subsequently transferred to additional refuse materials, propagating the pyrolytic reaction. Open flames within the landfill are considered unlikely. However, once the subsurface fire reaches the surface, open flames could occur.

Transfer of heat within the landfill environment is accomplished by conduction and/or convection. Conduction is heat transfer by direct contact, while convection is heat transfer by a circulating medium (liquid or gas). Conduction of heat in the landfill is limited to the surface area of the refuse undergoing oxidation. Combustible gases produced during pyrolysis near this zone may also be heated by conduction. Convective forces cause the hot gas to expand and rise through the landfill. When the hot gas comes in contact with cooler refuse material, heat is transferred by conduction.

The operation of LFG extraction systems (for either recovery or migration control) can result in air entering the landfill. Overdrawing extraction wells, especially those installed near the perimeter or a slope face, creates a situation where air can be drawn into the refuse mass. Open cracks and fissures in a landfill site surface facilitate drawing of air through the site cover.

Convection currents within the landfill (due to higher gas temperature) can establish a chimney effect and cause air to be drawn into the landfill.

Routine testing and adjustment of flow rates from extraction wells, as well as maintenance of the landfill site surface, are required to control air infiltration and the resultant potential for a subsurface fire. Obviously, the withdrawal of LFG at a rate faster than its production will result in air infiltration.

Identification of subsurface fire

Inspection of site surfaces for settlement resulting from subsurface void space can give an indication as to the location and extent of subsurface combustion. Distinguishing between settlement resulting from normal decomposition processes, as opposed to collapsing of upper refuse layers into a void space created by subsurface combustion, may be difficult. Surface settlement may provide no indication of subsurface fire if combustion is sufficiently deep within the landfill such that bridging supports upper refuse layers.

Venting of smoke through cover soils confirms the existence of subsurface combustion, but provides little information as to location of the fire. Channeling within the landfill can result in smoke venting at locations distant from the actual point of combustion. Depending on the location of subsurface fire, smoke could be drawn through the extraction system unnoticed.

CO presence may indicate fire

Analysis of venting and/or extracted gas for the presence of carbon monoxide (a product of incomplete combustion) can also identify the existence of subsurface fire. Gas analysis can be accomplished using portable equipment in the field, such as gas detector tubes, or via gas chromatography. Carbon monoxide concentrations in LFG exceeding a few parts per million should result in additional testing and observation for a possible fire.

Continued operation of an LFG extraction system with wells in the vicinity of subsurface fire can result in drawing the residue of combustion processes through the extraction system and eventual destruction of the well. Visual evidence can be observed in a thick, black, tar-like coating in header lines. Experience has shown that combustion temperatures can be high enough to destroy extraction system components (i.e., wells and header lines) while tar-like residues can coat valves and pump station components to a point where they become inoperable.

Monitor gas well temperatures

Regular monitoring of extraction well heads and header line gas temperatures can aid in locating the general region of subsurface combustion. For example, gas temperatures 45° F above baseline gas temperatures were observed at one site just prior to verification of a subsurface fire. The higher temperatures were recorded in a header line adjacent to the extraction well. The well was subsequently excavated and found to be partially destroyed by the subsurface fire.

Use of temperature sensing equipment, such as a linear pyrometer and/or a thermographic scanner, can aid in identification of the limits of subsurface combustion by providing a site surface temperature profile. The linear pyrometer gives a digital readout of surface temperatures with an accuracy of + 1° F. The hand-held instrument is portable, and allows rapid point source survey of site surfaces. A thermographic scan provides a real time infrared image of surface temperatures. The scan shows best resolution from locations elevated above a landfill site surface (e.g., an aerial scan).

The scan does not give quantitative temperature data, but rather an image with differences in intensity corresponding to areas exhibiting elevated surface temperatures with a resolution of 1° to 2° F. Use of thermographic scanners allows survey of large areas of a landfill in one view. The usefulness of these instruments is limited to near-surface combustion, and must be used at night to eliminate solar radiation at the heat source.

Bore for information

Subsurface borings into a suspected zone of combustion and logging of the materials excavated provides information on the extent and depth of the fire. Precautions must be taken to protect drilling personnel and equipment from high-temperature gas and refuse excavated. Due to the high cost of drilling, a drilling program should be developed (e.g., drilling at designated points in a grid pattern). The program should be implemented after preliminary identification of a suspected fire by one or more of the above methods.

Borings into and adjacent to a subsurface fire zone can serve as test wells to monitor subsurface temperature gradients. Subsurface temperature gradients can be obtained by the use of a thermocouple. If test wells are constructed using high pressure steel pipe and fittings, they can be used for subsequent injection of water and/or inert gas to aid in extinguishing the subsurface fire.

Controlling subsurface fires

Selection of a subsurface fire control technique is dependent on several factors, including depth, composition, and configuration of the landfill site; depth and size of the subsurface fire; site surface development; and type and operational requirements of the LFG extraction facilities. Control of subsurface fire requires either removal of the combustible material, elimination of the oxidizing agent (air supply), or cooling of the fire zone to temperatures below the ignition temperature. Available techniques for fire control all employ one or more of these three approaches.

The refuse material in the landfill represents the combustible material, and therefore its removal may be impractical. Depriving the subsurface fire of its air supply will terminate combustion. However, the insulating properties of the refuse materials will keep subsurface temperatures high, necessitating an extended cooldown period by natural heat dissipation. During this period (possibly with an order or magnitude of tens of years), any reintroduction of an air supply could result in regeneration of subsurface combustion. Given that LFG extraction is essential at the site, cooling of the fire zone may be essential to provide positive control of the fire.

Options for treatment

Techniques employed to control a subsurface fire and some criteria for selection are summarized in the table on page 48. Removal of waste is limited to shallow subsurface fires for practical reasons. The excavated material would be cooled by spreading and dousing the water or other fire retardant. Backfilling excavated areas would be accomplished with either the completely cooled refuse material or imported soil. Associated with excavation are potential problems with odor and particular/air pollution from the excavated materials. Excavating equipment and personnel must be protected from hazards associated with handling/removing burning refuse material and/or explosive and possible toxic gas emissions. Since site disruption could be extensive, this method of control would not be applicable for a developed landfill site. A favorable aspect would be to allow return of control and/or recovery extraction systems to their operational status in a relatively short time period.

Eliminating the air supply (i.e., smothering) subsurface combustion will deprive the process of needed oxygen. As previously discussed, LFG extraction wells, site surface cracks/fissures, and natural convection can provide the necessary pathway for air to enter a landfill site. In attempting to deprive subsurface fire of its air supply, the first step would be to reduce or shut down flow from extraction wells in the immediate vicinity of the combustion zone. Following this step, all settlement cracks and fissures in site cover soils should be sealed to prevent any passive influx of air. As refuse decomposition proceeds, LFG production will create positive pressures within the landfill, replacing any atmospheric oxygen present with LFG and therefore prevent further subsurface combustion.

At some sites, LFG recovery and/or migration control is critical, and extraction wells must be reactivated as soon as practical. Since reactivation of extraction wells could potentially draw air through cover soils to the zone of previous combustion resulting in reignition of subsurface fire, it may be advisable to take additional steps to seal site surfaces. These steps could include application of additional cover soils or synthetic membranes to further seal the site surface or side slopes. Subsequent to sealing the surface area, extraction wells can be slowly reactivated for desired control and/or recovery purposes. Stringent testing must coincide with reactivation of extraction wells to assure that regeneration of the subsurface fire does not occur. Sealing site surfaces in this manner lends itself to vacant sites where additional soil cover or installation of a membrane would not disrupt activities.

Inject water or gas

The principle involved in extinguishing subsurface fire by injecting water or an inert gas is to remove heat (and in the case of inert gas, displace oxygen) from the combustion zone. Injection can be used for both deep and shallow fires, and can be accomplished with minimal disruption to a developed site. High temperature and pressure rated steel pipe injection wells would be used as a conduit to deliver water/inert gas to the combustion zone. Injection of water and/or an inert gas such as CO_2 can produce a high-temperature, high-pressure steam and/or gas within the landfill as heat is transferred from the pyrolyzing refuse material. This high-pressure hot gas will likely vent through cracks in the site surface. Thus injecting water or an inert gas under pressure can result in the formation of cracks and fissures within the landfill that could allow air intrusion. Any openings formed must be resealed. Injection of water has the disadvantage of leachate formation, and therefore its use may not be acceptable in some situations.

Monitor temperatures to determine success

Following injection, monitoring of subsurface temperatures can determine whether the fire has been controlled. Repeated applications may be necessary to achieve complete control.

Many landfills contain the combustible materials, insulating characteristics, and other attributes necessary to allow autoignition (spontaneous combustion), and to support subsurface combustion with introduction of an air supply. Over withdrawal from LFG extraction systems for recovery and/or migration control (and air injection systems for migration control) can provide the air source. It is probable that many older landfills may have subsurface "hot spots" which could become fire zones with introduction of air supply.

Identification and size definition of subsurface fires is difficult, involving use of one or more assessment techniques. Selection of a fire control method is site-specific, and must take into consideration many factors, including the cost of the control technique as well as its impact on site development and LFG revenues.

Successful control of subsurface fires requires post-control monitoring to assure that fire regeneration does not occur. WA

Robert Stearns is president of SCS Engineers of Los Angeles, California. Galen Petoyan is project engineer for the same firm.

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IDENTIFYING AND CONTROLLING LANDFILL FIRES*

Robert P. Stearns† and Galen S. Petoyan†

(*Received 23 July 1984*)

Factors leading to subsurface landfill fires and fire identification and control techniques are discussed. The paper is oriented towards completed sanitary landfill sites containing active landfill gas (LFG) extraction systems for either recovery or migration control purposes. The fire identification and control techniques discussed can be applied to both developed and undeveloped former landfill sites.

The ignition and propagation of subsurface landfill fires are a function of factors which include waste composition and moisture content, available oxygen, and ambient pressure in the area of combustion.

Identification and size of a subsurface landfill fire can be determined by unusual or rapid site surface settlement, surface venting of smoke, detection of carbon monoxide in extracted LFG, accumulation of combustion residue in LFG collection header lines, and elevated LFG temperatures.

Subsurface landfill fire control techniques include excavation, smothering, and extinguishing with injections of water or inert gas.

Key Words—Subsurface landfill fire, landfill gas (LFG) recovery, LFG migration control, fire mechanics, fire ignition and propagation, autoignition, pyrolysis, subsurface fire identification, subsurface fire control, extinguishing landfill fires.

1. Introduction

This paper will discuss factors leading to subsurface landfill fires and fire identification and control techniques. The discussion is oriented towards completed sanitary landfill sites containing active extraction systems for either landfill gas (LFG) recovery or migration control. The fire control techniques can be applied to both developed and undeveloped former landfills.

With the advent of sanitary landfills, open burning ceased and solid wastes were compacted and buried with layers of soil. As a result open burning was replaced with the relatively slow biological decomposition of the waste materials with LFG production. LFG was soon recognized as both a safety hazard and as an energy recovery opportunity. As efforts are made to increase LFG recovery or to control LFG emissions or migration, subsurface fire problems can be expected to increase.

Some former burning dumps were converted to sanitary landfill operations years ago. Burning materials were covered with soil with the presumption that the fire would be smothered. Somewhat similar techniques are employed today when "hot loads" are delivered to a sanitary landfill. Typically, the burning materials are wetted with water or otherwise extinguished, then incorporated into the landfill.

These practices may result in "hot spots" (areas with elevated temperatures) within

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the landfill. These "hot spots" can become excellent candidates for subsurface fires with the addition of an air supply.

2. Overview of fire mechanics

Initial ignition and propagation of subsurface landfill fires is complex, and a function of many factors. These include waste composition and moisture content, available oxygen, ambient pressure in area of combustion, etc.

In general, as a combustible material is heated, either through biological decomposition or chemical oxidation, ignition will occur at some given temperature termed the ignition temperature for the material. The resulting heat of combustion will support flame spread under most conditions. Combustion will continue until at least one of the following occurs.

(1) The combustible material is consumed.
(2) The oxidizing agent (typically atmospheric oxygen) is depleted.
(3) Heat acting as the ignition source is removed faster than it is produced.

2.1. *Biological decomposition*

Organic waste materials (containing primarily carbon and hydrogen) buried in a landfill decompose aerobically (in the presence of oxygen) or anaerobically (absence of oxygen), and release heat in the process. For most materials, the rate of biological decomposition is slow. Produced heat is transferred to surroundings as it is formed and a stable, but somewhat elevated, temperature occurs as decomposition proceeds.

2.2. *Chemical oxidation*

Spontaneous ignition (autoignition) of a combustible material can occur if enough air is available and higher temperatures exist to permit chemical oxidation. Under highly insulating conditions the heat produced is retained and the chemical oxidation rate continues to increase. Under these conditions, the combustible material will eventually reach its ignition temperature and spontaneous combustion will occur. The rate of heat generation, available air supply, and the insulating properties of the surrounding materials all influence whether chemical oxidation will result in temperatures reaching, and/or exceeding, ignition temperatures of the combustible material.

2.3. *Landfill fire ignition*

Wastes placed in a landfill initially undergo biological decomposition aerobically, producing carbon dioxide (CO_2), water, and heat which can result in maximum landfill temperatures in the 60–71 °C (140–160 °F) range. As available oxygen is consumed (and assuming a new source of oxygen is not available), biological decomposition becomes anaerobic with resultant production of methane (CH_4) and CO_2. Heat is also a product of anaerobic decomposition. Temperatures will remain in the 60–71 °C (140–160 °F) range if the insulating properties of the waste materials are high. In loosely compacted or dry landfills the heat retention is inadequate and temperatures usually return to the 21–43 °C (70–110 °F) range.

The high insulating characteristics of in-place refuse causes retention of heat within the refuse mass. Increasing temperatures cause an increase in the rate of chemical oxidation of refuse (which initially occurs simultaneously with biological decomposition processes). This heating can continue past the limit of biological survival of the bacteria. Heating to the point of spontaneous combustion is the result of continued chemical oxidation, which follows the initial heat generated by biological decomposition. A continuous source of oxygen is necessary for this process to proceed to the point of ignition.

As temperatures within the landfill increase, the refuse material undergoes pyrolysis, i.e. chemical decomposition of matter through the action of heat. Pyrolysis converts the refuse material to a black carbonaceous char. Continued air supply bringing additional oxygen in contact with pyrolyzing refuse causes the char material to become red hot. The heat generated is subsequently transferred to additional refuse materials, propagating the pyrolytic reaction. Open flames within the landfill are considered unlikely. However, once the subsurface fire reaches the surface, open flames could occur.

Transfer of heat within the landfill environment is accomplished by conduction and/or convection. Conduction is heat transfer by direct contact while convection is heat transfer by a circulating medium (liquid or gas). Conduction of heat in the landfill is limited to the surface area of the refuse undergoing oxidation. Combustible gases produced during pyrolysis near this zone may also be heated by conduction. Convective forces cause the hot gas to expand and rise through the landfill. When the hot gas comes in contact with cooler refuse material, heat is transferred by conduction.

2.4. *Sources of air*

The operation of LFG extraction systems (for either recovery or migration control) can result in air entering the landfill. Overdrawing extraction wells, especially those installed near the perimeter or a slope face, creates a situation where air can be drawn into the refuse mass. Open cracks and fissures in a landfill site surface facilitate drawing of air through the site cover.

Convection currents within the landfill (due to higher gas temperature) can establish a chimney effect and cause air to be drawn into the landfill.

Routine testing and adjustment of flow rates from extraction wells, as well as maintenance of the landfill site surface, are required to control air infiltration and the resultant potential for a subsurface fire. Obviously, the withdrawal of LFG at a rate faster than its production will result in air infiltration.

3. Identification of subsurface fire

Identification and size determination for a subsurface fire can be difficult. A subsurface fire is typically indicated by:

unusual or rapid settlement,
venting of smoke,
carbon monoxide in extracted LFG,
combustion residue in header lines,
elevated LFG temperatures.

Determination of the location and areal extent of the subsurface fire can involve several approaches. These are:

thermographic scans,

excavation or borings to allow visual examination of refuse.
installation of test wells to allow monitoring of subsurface temperature gradients.

Inspection of site surfaces for settlement resulting from subsurface void space can give an indication as to the location and extent of subsurface combustion. Distinguishing between settlement resulting from normal decomposition processes, as opposed to collapsing of upper refuse layers into a void space created by subsurface combustion, may be difficult. Surface settlement may provide no indication of subsurface fire if combustion is sufficiently deep within the landfill such that bridging supports upper refuse layers.

Venting of smoke through cover soils confirms the existence of subsurface combustion but provides little information as to location of the fire. Channelling within the landfill can result in smoke venting at locations distant from the actual point of combustion. Depending on the location of subsurface fire, smoke could be drawn through the LFG extraction system unnoticed.

Analysis of venting and/or extracted LFG for the presence of carbon monoxide (a product of incomplete combustion) can also identify the existence of subsurface fire. Gas analysis can be accomplished using portable equipment in the field, such as gas detector tubes, or via gas chromatography. Carbon monoxide concentrations exceeding a few parts per million in LFG should result in additional testing and observation for a possible fire.

Continued operation of an LFG extraction system with wells in the vicinity of subsurface fire can result in drawing the residue of combustion processes through the extraction system and eventual destruction of the well. Visual evidence can be observed in a thick, black, tar-like coating in header lines. Experience has shown that combustion temperatures can be high enough to destroy extraction systems components (i.e. wells and header lines) while tar-like residues can coat valves and pump station components to a point where they become inoperable.

Regular monitoring of extraction well heads and header line gas temperatures can aid in locating the general region of subsurface combustion. For example, gas temperatures 45°F above baseline gas temperatures were observed at one site just prior to verification of a subsurface fire. The higher temperatures were recorded in a header line adjacent to the extraction well. The well was subsequently excavated and found to be partially destroyed by the subsurface fire.

Use of temperature sensing equipment, such as a linear pyrometer and/or a thermographic scanner, can aid in identification of the limits of subsurface combustion by providing a site surface temperature profile. The linear pyrometer gives a digital readout of surface temperatures with an accuracy of ± 1°F. The hand-held instrument is portable and allows rapid point source survey of site surfaces. A thermographic scan provides a real time infrared image of surface temperatures. The scan shows best resolution from locations elevated above a landfill site surface (e.g. an aerial scan).

The scan does not give quantitative temperature data, but rather an image with differences in intensity corresponding to areas exhibiting elevated surface temperatures with a resolution of 0.5–1.0°C (1–2°F). Use of thermographic scanners allows survey of large areas of a landfill in one view. The usefulness of these instruments is limited to near-surface combustion, and they must be used at night to eliminate solar radiation as the heat source.

Subsurface borings into a suspected zone of combustion and logging of the materials excavated provides information on the extent and depth of the fire. Precautions must be taken to protect drilling personnel and equipment from high-temperature gas and refuse excavated. Due to the high cost of drilling, a drilling program should be developed (e.g. drilling at designated points in a grid pattern). The program should be implemented after preliminary identification of a suspected fire by one or more of the above methods.

Borings into and adjacent to a subsurface fire zone can serve as test wells to monitor subsurface temperature gradients. Subsurface temperature gradients can be obtained by the use of a thermocouple. If test wells are constructed using high pressure steel pipe and fittings, they can be used for subsequent injection of water and/or inert gas to aid in extinguishing the subsurface fire.

4. Control of subsurface fires

Selection of a subsurface fire control technique is dependent on several factors, including depth, composition, and configuration of the landfill site; depth and size of the subsurface fire; site surface development; type and operational requirements of the LFG extraction facilities; etc. Control of subsurface fire requires either removal of the combustible material, elimination of the oxidizing agent (air supply), or cooling of the fire zone to temperatures below the ignition temperature. Available techniques for fire control all employ one or more of these three approaches.

The refuse material in the landfill represents the combustible material, and therefore its removal may be impractical. Depriving the subsurface fire of its air supply will terminate combustion; however, the insulating properties of the refuse materials will keep subsurface temperatures high, necessitating an extended cool down period by natural heat dissipation. During this period (possibly with an order of magnitude of tens of years) any reintroduction of an air supply could result in regeneration of subsurface combustion. Given that LFG extraction is essential at the site, cooling of the fire zone may be essential to provide positive control of the fire.

Techniques employed to control a subsurface fire and some criteria for selection are summarized on Table 1. Removal of waste is limited to shallow subsurface fires for practical reasons. The excavated material would be cooled by spreading and dousing with water or other fire retardant. Backfilling excavated areas would be accomplished with either the completely cooled refuse material or imported soil. Associated with excavation are potential problems with odour and particulate/air pollution from the excavated materials. Excavating equipment and personnel must be protected from

TABLE 1
Subsurface landfill fire control technique selection

	Applicability					
	Fire depth		Extraction system		On-site development	
Fire control technique	< 9 m (< 30 ft)	> 9 m (> 30 ft)	Control	Recovery	Vacant	Developed*
Excavation	Yes	No	Yes	Yes	Yes	No
Smother	Yes	No	Yes	Yes	Yes	Yes
Extinguish						
Inject inert gas	Yes	Yes	Yes	Yes	Yes	Yes
Inject water	Yes	Yes	No	Yes	Yes	Yes

*Site surface developed as golf course, drive-in theater, storage facility, etc., requiring public site occupancy.

hazards associated with handling/removing burning refuse material and/or explosive, and possibly toxic, gas emissions. Since site disruption could be extensive, this method of control would not be applicable for a developed landfill site. A favourable aspect is that it would allow return of control and/or recovery extraction systems to their operational status in a relatively short time period.

Eliminating the air supply (i.e. smothering) subsurface combustion will deprive the process of needed oxygen. As previously discussed, LFG extraction wells, site surface cracks/fissures, and natural convection can provide the necessary pathway for air to enter a landfill site. In attempting to deprive subsurface fire of its air supply the first step would be to reduce or shut down flow from extraction wells in the immediate vicinity of the combustion zone. Following this step all settlement cracks and fissures in site cover soils should be sealed to prevent any passive influx of air. As refuse decomposition proceeds LFG production will create positive pressures within the landfill, replacing any atmospheric oxygen present with LFG and therefore prevent further subsurface combustion.

At some sites LFG recovery and/or migration control is critical and extraction wells must be reactivated as soon as practical. Since reactivation of extraction wells could potentially draw air through cover soils to the zone of previous combustion resulting in reignition of subsurface fire, it may be advisable to take additional steps to seal site surfaces. These steps could include application of additional cover soils of synthetic membranes to further seal the site surface or side slopes. Subsequent to sealing the surface area, extraction wells can be slowly reactivated for desired control and/or recovery purposes. Stringent testing must coincide with reactivation of extraction wells to assure that regeneration of the subsurface fire does not occur. Sealing site surfaces in this manner lends itself to vacant sites where additional soil cover or installation of a membrane would not disrupt activities.

The principle involved in extinguishing subsurface fire by injecting water or an inert gas is to remove heat (and in the case of inert gas, displace oxygen) from the combustion zone. Injection can be used for both deep and shallow fires, and can be accomplished with minimal disruption to a developed site. High temperature and pressure rated steel pipe injection wells would be used as a conduit to deliver water/inert gas to the combusion zone. Injection of water and/or an inert gas such as CO_2 can produce a high-temperature, high-pressure steam and/or gas within the landfill as heat is transferred from the pyrolyzing refuse material. This high-pressure hot gas will likely vent through cracks in the site surface. Thus, injecting water or inert gas under pressure can result in the formation of cracks and fissures within the landfill that could allow air intrusion. Any openings formed must be resealed. Injection of water has the disadvantage of leachate formation, and therefore its use may not be acceptable in some situations.

Following injection, monitoring of subsurface temperatures can determine whether the fire has been controlled. Repeated applications may be necessary to achieve complete control.

5. Summary

Many landfills contain the combustible materials, insulating characteristics, and other attributes necessary to allow autoignition (spontaneous combustion), and to support subsurface combustion with introduction of an air supply. Over withdrawal from LFG extraction systems for recovery and/or migration control (and air injection systems for migration control) can provide the air source. It is probable that many older landfills may have subsurface "hot spots" which could become fire zones with introduction of air supply.

Identification and size definition of subsurface fires is difficult, involving use of one or more assessment techniques. Selection of a fire control method is site-specific and must take into consideration many factors including the cost of the control technique as well as its impact on site development and LFG revenues.

Successful control of subsurface fires requires post-control monitoring to assure that fire regeneration does not occur.

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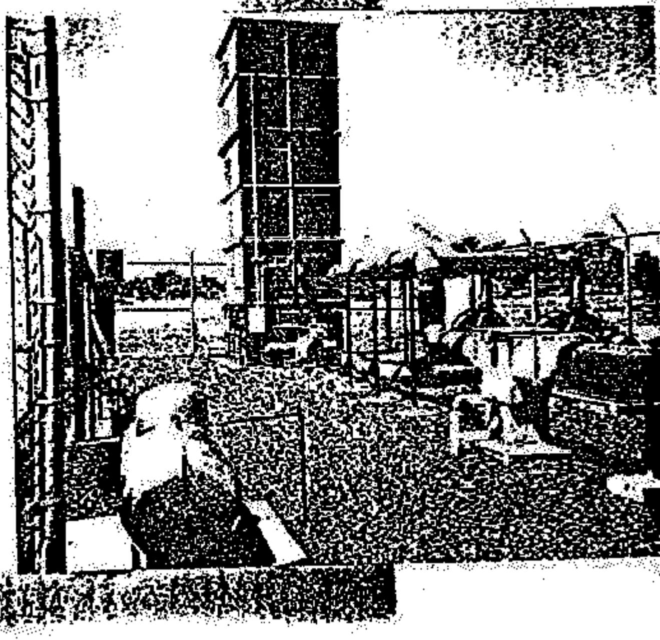
APPENDIX B

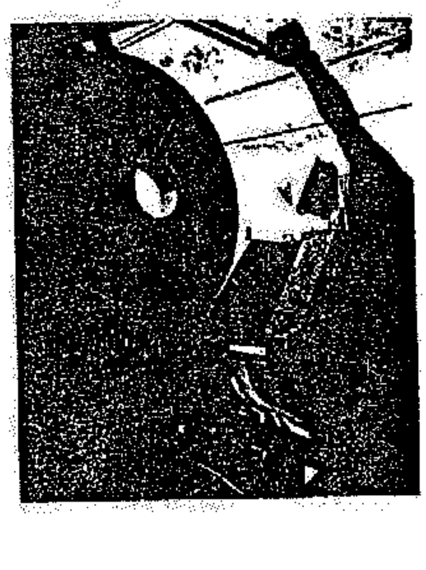
BROCHURES AND QUALIFICATIONS FOR SCS ENGINEERS

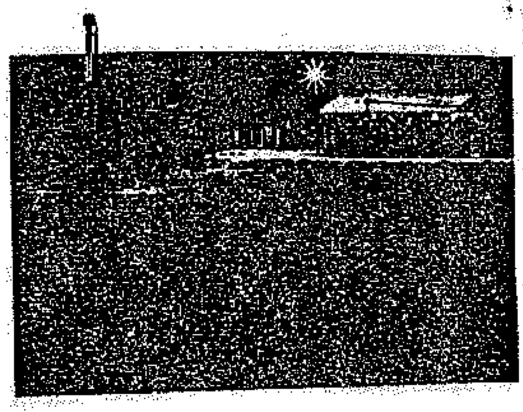
SCS ENGINEERS

Landfill Gas Control and Recovery

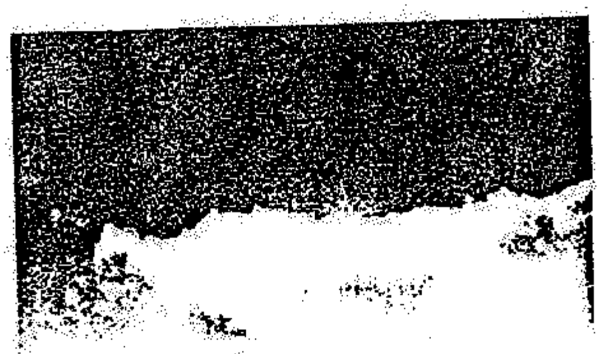
Landfill-derived methane gas is used as fuel in boilers at this civic recreation/conference center site located in the City of Industry, California. This project was selected as the Outstanding Civil Engineering Achievement in 1981 by the American Society of Civil Engineers.







SCS was awarded the Florida Engineering Society's 1989 Engineering Excellence Award for the design of a landfill gas odor and migration control system in Seffner, Florida.



An SCS subsidiary, SCS Field Services, provides construction, operation, and maintenance of landfill gas systems.

Landfill Gas

Anaerobic decomposition of organic solid waste in the landfill environment produces landfill gas (LFG). LFG mainly consists of methane and carbon dioxide, both of which are odorless. Trace concentrations of other volatiles, often malodorous or toxic gases, are also found in LFG.

LFG can migrate through soil into structures located on or near landfills. Since methane presents a fire or explosive threat, LFG must be controlled to protect property, and public health and safety. Also, many jurisdictions require landfill owners/operators to reduce reactive organic gas emissions to improve regional air quality. Thus, engineered solutions are needed to efficiently and safely monitor, collect, and process landfill gas.

A positive side to LFG control is energy recovery. Today's technology allows a landfill owner/operator to recover the energy in LFG while reducing gas emissions. Revenue from the sale of LFG or electricity generated using LFG as a fuel can offset costs for landfill environmental compliance and/or closure.

SCS Engineers - A Quarter Century of Experience

Since 1970, SCS Engineers has been a national leader in the planning, permitting, investigation, design, construction, and operation of LFG control and energy recovery systems. Our LFG designs are working at hundreds of locations around the world.

SCS specializes in: (a) engineering design services and investigations; and (b) design/build projects. Working through its subsidiary SCS Field Services, SCS provides design/build services for construction of landfill gas systems. A design/build project typically combines the design and construction steps into a single contract, resulting in an expedited construction schedule and reduced overall costs.

RCRA Subtitle D

The Resource Conservation and Recovery Act (RCRA) establishes landfill design and performance standards under Subtitle D. Subtitle D requires monitoring of landfill gas, and establishes performance standards for combustible gas migration control. Landfill owners/operators must:

- Establish LFG monitoring programs. Use of gas monitoring probes is typical.
- Monitor for subsurface migration of combustible gas on a quarterly basis.
- Maintain combustible gas concentrations under 5 percent in soil at the property line, and under 1.25 percent in facility structures.
- Mitigate gas hazards if conditions are not in compliance.

SCS has designed and implemented the types of LFG programs required under Subtitle D at hundreds of landfills.

New Source Performance Standards

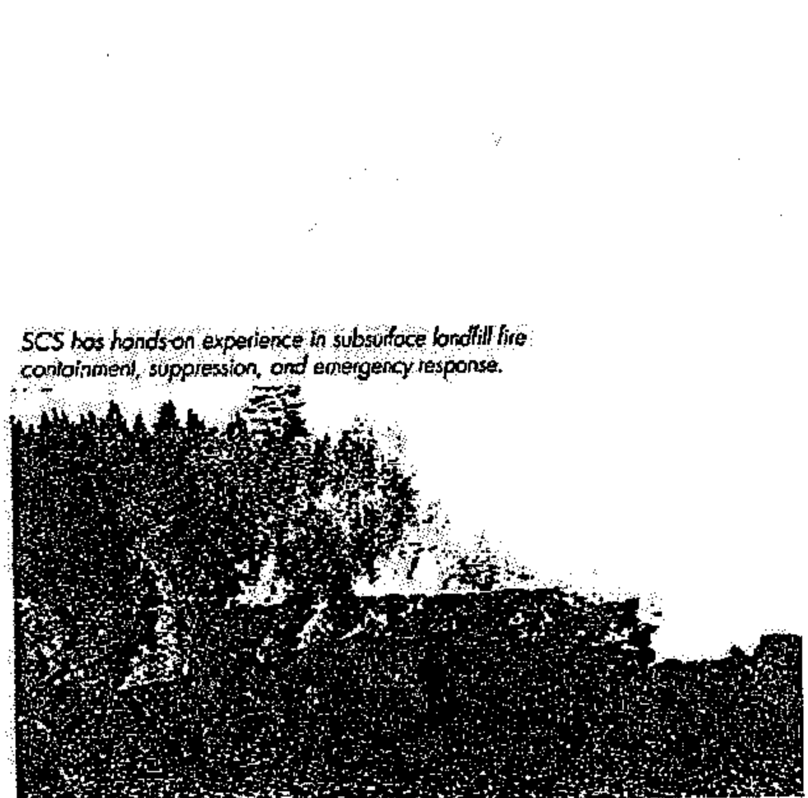
The U.S. EPA has proposed control of surface LFG emissions under the Clean Air Act. The New Source Performance Standards (NSPS) will require LFG testing and collection system installations at many sites, even those otherwise in compliance with RCRA Subtitle D. NSPS will require landfill owners/operators to:

- Estimate total LFG emissions using sophisticated gas models, laboratory analyses, and gas pump tests.
- Install comprehensive gas collection systems throughout the landfill at any site shown to have high emissions of non-methane organic compounds.
- Perform long-term operation and record keeping of such landfill gas systems.

SCS offers the services required for NSPS compliance including engineering, test services, laboratory analysis, gas system design, system installation, and operations.

SCS professionals conduct field and laboratory testing to access LFG quantities, characteristics, current and future production rates, and optimal recovery system configurations.

SCS has hands-on experience in subsurface landfill fire containment, suppression, and emergency response.



SCS offers comprehensive landfill gas services to assist you in meeting regulatory compliance and budgetary constraints.

Combustible Gas Migration Control

- Gas Monitoring
- Control System Design
- Landfill Underground Fire Control
- Long Term Monitoring and Certification
- Permits and Regulatory Support

Energy Recovery

- Feasibility Studies
- Gas Modeling
- Field Test Programs
- Market Investigations
- System Design
- Gas Sale Contract Services
- Construction and Operation Services
- Long-Term Monitoring and Certification

Odor Abatement

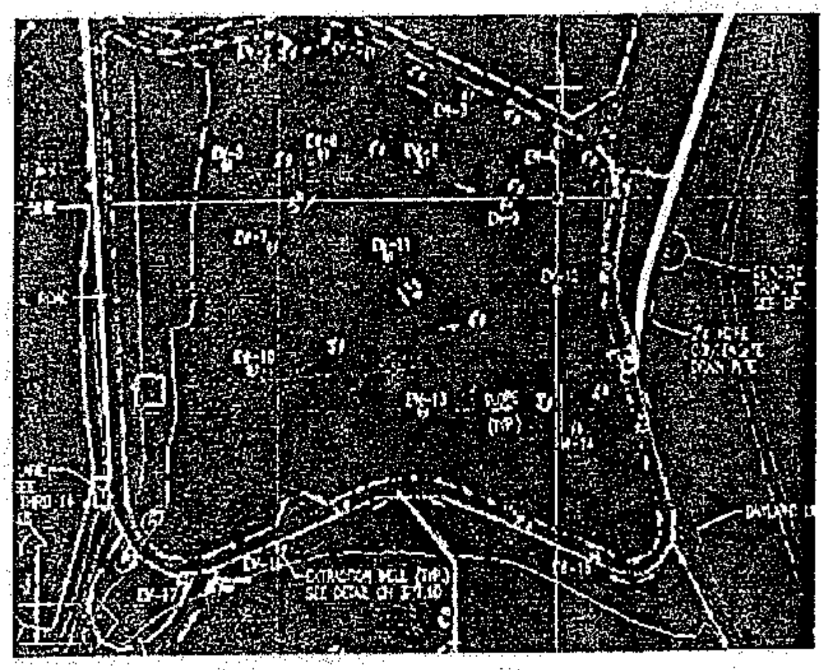
- Odor Assessments
- Odor Abatement Design
- Construction Services
- Start Up and Well Field Balancing
- Long-Term Monitoring and Certification
- Permits and Regulatory Support

Toxic Gases

- Gas Characterization
- Air Modeling
- Stack Testing
- Permits and Regulatory Support

Design/Build

SCS Field Services can construct and operate your landfill gas collection system, and provide comprehensive closure and postclosure operation and maintenance services.



SCS has extensive expertise in LFG technology, ranging from feasibility studies and collection systems design to operation and maintenance of control and recovery systems.

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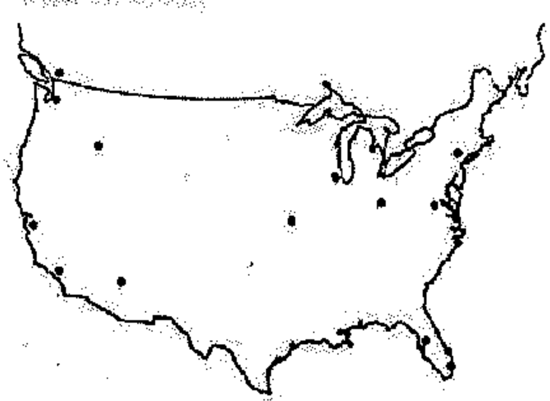

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EXHIBIT B

FEE SCHEDULE
LANDFILL FIRE MITIGATION
LAIDLAW BRIDGETON SANITARY LANDFILL

Environmental Consultants

2000 Fe[illegible] Road
Suite 200
Cincinnati, Ohio 45202-1416

513 421-5353
FAX 513 421-2847

SCS ENGINEERS

January 1, 1994

LAIDLAW FEE SCHEDULE

(Effective January 1, 1994 through June 30, 1994)

	Rate/Hour
Project Director	$135
Project Manager	99
Senior Professional	89
Project Professional	71
Staff Professional	56
Associate Professional	48
Assistant Professional	40
Designer	48
Drafter/Graphics	42
Technician	40
Secretarial/Administrative	38

General Terms:

1. Rates for principals of the firm are negotiated on a project-specific basis and range from $130 to $170 per hour depending on experience and qualifications.

2. Scheduled rates are effective through June 30, 1994. Work performed thereafter is subject to a new Fee Schedule.

3. Scheduled labor rates include overhead, administration and profit. Costs for outside consultants and subcontractors, and for job-related employee travel and subsistence, external reproduction, telephone, equipment, and supplies are billed at actual cost plus a 15 percent administrative fee. Internal costs such as fax, computer, CADD, field equipment, and internal reproduction will be billed at cost.

4. Charges for field equipment and instruments will be in accordance with the SCS Standard Fee Schedule for Field Equipment in effect at the time the work is performed.

5. Invoices will be prepared monthly or more frequently for work in progress unless otherwise agreed. Invoices are due and payable upon receipt. Invoices not paid within 45 days are subject to a service charge of 1 percent per month on the unpaid balance.

6. Payment of SCS invoices for services performed will not be contingent upon the client's receipt of payment from other parties, unless otherwise agreed in writing. Client agrees to pay legal costs, including attorney's fees, incurred by SCS in collecting any amounts past due and owing on client's account.

7. For special situations, such as expert court testimony and limited consultation, hourly rates will be on an individually negotiated basis.

Environmental Consultants

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513 421-5353
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SCS ENGINEERS

January 1, 1994

LAIDLAW FEE SCHEDULE FOR FIELD EQUIPMENT

(Effective January 1, 1994 through June 30, 1994)

	Rate
Extraction Test Blower/Motor	$100/day, 300/week
GEM-500 Analyzer	75/day
Methane Meter	20/day
Oxygen Meter	30/day
Carbon Dioxide Fyrite Indicator	15/day
Pressure Measurement Device (magnehelics, manometers, etc.)	15/day
Flow Measurement Device (orifice plates, flow meters, etc.)	25/day
Gas Temperature Measurement Device (digital read-out with probe)	15/day
Detector Tube (hydrogen sulfide, carbon monoxide, etc.)	5/each
Vacuum Sampling Pump - Draeger Pump	10/day
- Low Capacity MSA Pump	15/day
- High Capacity Bellows Pump	40/day
Grundfos 2 in. Groundwater Pump	100/day
Punch Bar	15/day
Gas Sampling Burette	10/each
Gas Sampling Bag	15/each
Photoionization Detector	75/day
Water Level Indicator	20/day
ph/Conductivity/Temperature Meter	25/day
Well Bailer	15/day
Disposable Well Bailers	15/each
Field Groundwater Filter Unit/Pump	20/day
Disposable Groundwater Filters	15/each
Buckets (5 gallon disposable)	6/each
Soil Sampler	10/day
Soil Sample Container	4/each
VOA Sample Containers	3/each
QA/QC Supplies	15/day
Level B SCBA (used on-site)	60/day
(available on-site and unused)	20/day
Level C North Full-Face Respirator (used on-site)	20/day
(available on-site and unused)	6/day
Level C North Half-Face Respirator (used on-site)	10/day
(available on-site and unused)	2/day
Latex Over-Boots (disposable)	5/pair
Tyvek Suit (disposable)	6/each
Scales - Spring (0-70 lb)	50/week
- Spring (0-100 lb)	50/week
- Platform	100/week
- Truck/Axle	300/week

LAIDLAW FEE SCHEDULE FOR FIELD EQUIPMENT (continued)

General Terms:

1. Rates are in effect until June 30, 1994. Any work performed after that date is subject to a new Schedule of Fees.

2. Equipment usage rates are exclusive of freight charges to and from the project site. Freight is an additional expense chargeable to the client.

3. Rates for extraction test blower/motor are exclusive of expenses for electric line installation, electricity, generators, or fuel. These expenses are charged to the client separately.

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SCS ENGINEERS

January 1, 1994

LAIDLAW FEE SCHEDULE
IN-HOUSE COSTING RATES
(Effective January 1, 1994 through June 30, 1994)

CADD Computer	$25/hour
Word Processing Computer	$10/hour
Facsimile	$1/page
Reproduction (8.5 in. × 11in.)	$0.10/page
Reproduction (blueline prints)	$1.50/sheet
Reproduction (vellum reproducibles)	$3/sheet
Reproduction (nulon reproducibles)	$10/sheet

EXHIBIT C

PROJECT SCHEDULE
LANDFILL FIRE MITIGATION
LAIDLAW BRIDGETON SANITARY LANDFILL

Environmental Consultants

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SCS ENGINEERS

March 29, 1994
File No. 0593034

RECEIVED
MAR 30 1994

SWMP

POSTED

Mr. Dennis Wike
Environmental Manager
Laidlaw Waste Systems, Inc.
P.O. Box 97
Cahokia Road
Roxana, Illinois 62084

Subject: Task 4 Report
Assessment of Results/Recommendations for Future Action
Subsurface Combustion at Laidlaw Bridgeton Landfill

Dear Mr. Wike:

This letter provides you with a summary of our activities to date at the Bridgeton Landfill. Work included: infrared thermography of site, installation of temperature probes, and monitoring of temperature probes. A discussion and our recommendations are also included.

TASK 1 - CONDUCT INFRARED THERMOGRAPHY

On March 9, 1994, SCS Engineers performed an infrared thermography of the Bridgeton Landfill. The purpose of the infrared thermography was to gather additional information which would be used in helping make a determination as to the horizontal or lateral extent of the subsurface fire at the Bridgeton Landfill.

Infrared thermography is a non-contact, non-invasive means of producing visible images from the invisible or infrared heat energy emitted from an object. Infrared thermography (also known as infrared imaging) consists of an infrared scanner with optics transparent only to infrared radiation and a real-time computer display monitor, similar to a portable television.

The scanner converts the radiated heat that is allowed to pass through the optics to create an electronic signal. The signal is then turned into a real time thermal image on the computer screen of the display unit. The thermal image is composed of a gray scale with continuous tones ranging from black to white. Areas of higher relative temperature normally appear lighter and areas of lower relative temperature normally appear darker. Intermediate shades of gray indicate variations between the extremes of temperature the unit is set to detect. Color gradations can also be used and were, in fact, used some on this project; however, most of the effort was done using black and white which produced good results.

With the equipment used, it is possible to observe, quantify, and record the thermal image of the surface of an object whose temperature is between -20°C and +2,000°C. The sensitivity of the imaging equipment is such that it has the capacity to detect surface temperature differences between two given objects to an accuracy of ±0.05°C. For this effort, the low end of the temperature scale was generally set between 15 and 25°F, and the upper end was set between 38 and 41°F.

On this project, a hand-held scanner was used. Two representatives of Entech Engineering, a representative from SCS Engineers, and the helicopter pilot performed an approximate 1-1/2 hour flyover of the site on the morning of Wednesday, March 9, 1994. The helicopter used was a Bell Jet Ranger III. The two representatives from Entech Engineering sat in the back two seats with the scanner and electronic equipment. The representative from Entech holding the camera sat on the pilot side of the aircraft. The scan was done with the camera held in his right hand, and held as far out the helicopter window as possible.

Both the representative from SCS and the other Entech representative watched the image on television monitors and through verbal commands to the camera operator directed the movement and position of the camera. Images were obtained both with the helicopter in a hovering position, and in a moving position flying both the perimeter of the entire site and the perimeter of the quarry area.

The initial 1/3 to 1/2 of the video tape represents various views of the small quarry area near the blower flare station where areas of fire have been noted and/or suspected in the past. Three bright white circular spots predominate in the views of this area. The two that are close together are the existing ground flare and candle flare for the gas collection system. Obviously, these burning landfill gas (LFG) sources are excellent infrared emitters and show up as the bright white spots. The third bright white spot that predominates is not quite as big as the other two, and is an area along the north quarry wall at about the midpoint where flames are visible at the ground and rock wall interface. There appear to be small warm areas in the vicinity of this flame area, and they are isolated to locations near the rock wall landfill cover interface.

In summary, the infrared thermography provided supporting information to the theory that the fire is limited to the interface of the rock wall and landfill cover. It does not provide any evidence that the fire has extended out from the rock wall. This subject will be addressed in the Task 2 temperature probe installation work described below.

TASK 2 - INSTALL TEMPERATURE PROBES

Six monitoring temperature probes (T-1 through T-6) were installed on March 9, 10, and 11, 1994, by United Geosciences of St. Louis, Missouri, in the areas of surface and subsurface combustion. These probes were installed approximately 20 to 35 ft from the quarry wall. T-1 through T-4 are along the northwest quarry wall. T-1 is near TRW-1.

T-2 and T-3 are near TRW-2. T-4 is near TRW-3. T-5 and T-6 are along the southwest quarry wall. T-5 is near TRW-3. T-6 is downslope from T-6. The locations of T-1 through T-6 are shown in Exhibit 1. Boring and backfill logs are in Appendix A.

Surface and subsurface combustion is currently taking place from cracks along the quarry wall near T-2 and T-3. Surface combustion is evidenced by open flame. Subsurface combustion is evidenced by extremely high temperature greater than 800°F inside cracks up to approximately 20 ft from the open flame. Smoke emanating from the cracks is also evidence of subsurface combustion. Black soot and baked, brick-like dirt along the quarry wall indicates past and present surface and subsurface combustion. A total of approximately 100 ft of quarry wall near TRW-2 has or has had surface and subsurface combustion.

Smoke from subsurface combustion has also been observed along an approximately 100 ft section of the quarry wall in the vicinity of T-6. Black soot and some blackened dirt is along cracks of the quarry wall. Smoke has not been detected in several months.

The temperatures of refuse of T-1, T-4, T-5, and T-6 were generally less than 100°F which is typical of landfills. The temperatures of T-2 and T-3 were 100 to 140°F which is higher than typical refuse in landfills. The temperature may be higher because of the surface and subsurface combustion along the quarry wall. There was no evidence from the refuse drill hole cuttings that subsurface combustion was or had taken place at these locations (such as combusted/charred refuse).

T-1, T-2, T-4, and T-5 are vertical probes. The purpose was to determine the vertical and horizontal extent of subsurface combustion (if any) in the refuse away from the quarry wall. T-3 and T-6 were drilled towards the quarry wall at angles of approximately 20 and 30 degrees from the vertical, respectively. The purpose was to determine the vertical extent of subsurface combustion (if any) in the refuse beneath the quarry wall.

The temperature probes were drilled with 4-1/4 inch I.D. and 7 inch O.D. hollow-stem augers. T-1, T-3, and T-5 were drilled to a depth of 18 ft below the surface. T-2 was drilled to a depth of 50 ft below the surface. T-3 was drilled 40 ft at an angle from the vertical. T-6 was drilled 22 ft at an angle. A drill rig (CME 55) used by United Geosciences was capable of drilling vertical and angle borings.

The temperature probes were constructed with 1-1/2 inch diameter, flush joint, iron pipe. Slotted iron pipe was used from 5 to 8 ft below the surface to the bottom of the boring. Slots were cut into the iron pipe with a cutting torch. Solid iron pipe was above the slotted iron pipe to approximately 3 ft above the surface. Pea gravel was placed around the annular space of the slots. A bentonite seal was placed above the pea gravel to reduce the amount of vertical migration of gases in the borehole. Monitoring ports consisting of quick connect valves were installed in 1-1/2 inch PVC slip caps at the top of the probes. They allow for measuring gas composition and pressure with instruments.

TASK 3 - MONITOR TEMPERATURE PROBES

Monitoring was conducted on T-1 through T-6 for temperature with depth, pressure, and gas concentrations. Temperature was measured with a thermocouple and digital readout. The thermocouple has a length of approximately 100 ft. The slip cap was removed from the top of the probes and the thermocouple was lowered into the probes. Temperature readings were taken every 2 ft to the bottom of the probe.

Pressure and gas composition for methane, carbon dioxide, oxygen, and nitrogen were measured with a GEM-500 Gas Monitor. This instrument was fastened to the quick connect valves installed in the slip cap at the top of the probes. Readings were then taken.

Carbon monoxide was measured with Draeger tubes. Both tips of the tubes were broken off and inserted into a Draeger pump with the flow arrow pointed towards the pump. The quick connect valve was removed and the tube was inserted through the cap. Gas was drawn through the tubes based on the number of strokes (pumps) directed on the scale along the tube. The result was the amount of discoloration on the Draeger tube scale.

Temperature readings were taken on March 14, 15, and 16. Pressure and gas composition readings were taken on March 17. The data recorded is shown in Appendix B. The average, maximum, and minimum temperatures for each probe are also shown. The average, highest, and lowest temperatures of each probe were relatively consistent during this period.

The subsurface temperatures show a high variability with depth. The lowest temperatures are near the surface where the surface is cooler. The temperatures generally increase with depth. The highest temperatures in T-1, T-2, T-4, T-5, and T-6 are near the bottom of the probe. The highest temperature in T-3 is from 12 to 20 ft below the top of the probe. The temperatures in T-3 then decrease towards the quarry wall where the temperature is cooler.

The subsurface temperatures also show a high variability from probe to probe. T-1, T-5, and T-6 are relatively cool. The average and highest temperature of T-1, T-5, and T-6 are significantly lower than T-2, T-3, and T-4. The average and highest temperatures on March 16 for T-1, T-5, and T-6 were 92 and 106, 87 and 110, and 75 and 100 degrees F, respectively. T-4 was warmer with the average and highest temperature of 93 and 123 degrees F, respectively. T-2 and T-3 were relatively warm. The average and highest temperatures were 127 and 134 degrees F for T-2, and 121 and 142 degrees F for T-3. T-2 and T-3 are near the active area of surface and subsurface combustion.

The methane, carbon dioxide, oxygen, and nitrogen concentrations taken on March 17 are typical for LFG (see Appendix B). The ranges of methane, carbon dioxide, oxygen, and nitrogen were 50.4 to 64.8; 34.4 to 42.4; 0.1 to 2.5 percent by volume and 0 to 6.7 percent by volume, respectively. Pressures were relatively low ranging from 0 to 0.1 inches of water. The carbon monoxide contents ranged from 5 to 15 ppm by volume. The concentrations of carbon monoxide are significantly lower than on landfills where SCS has mitigated active subsurface combustion.

DISCUSSION

Temperature levels and carbon monoxide are indicators of active subsurface combustion. Temperatures exceeding 175 degrees F are often measured in and near the combustion area in landfills where SCS has mitigated subsurface combustion at other sites. Temperatures as low as approximately 120 degrees F may indicate a nearby source of subsurface combustion. Temperatures of approximately 100 to 140 degrees F are commonly found in deep landfills such as the Bridgeton Sanitary Landfill, where heat can concentrate because of the insulation ability of refuse. Temperatures of less than 100 degrees F are more typical for LFG.

Carbon monoxide concentrations exceeding 0.5 percent (5,000 ppm) by volume are often measured in and near the combustion area in other landfills where SCS has mitigated active subsurface combustion. Carbon monoxide concentrations as low as approximately 250 ppm by volume may also indicate a nearby source of subsurface combustion. Carbon monoxide concentrations lower than approximately 250 ppm by volume may be:

- Residual carbon monoxide from previous subsurface combustion.
- Carbon monoxide from a distant area of subsurface combustion.
- "Interference gases" detected in the Draeger tubes.

The temperatures and carbon monoxide concentrations in T-1, T-4, T-5, and T-6 indicate that active subsurface combustion in refuse is not currently taking place in these areas along the quarry wall. The higher temperatures in T-2 and T-3 may represent typical landfill temperatures or a nearby source of surface or subsurface combustion. The temperature increase with depth in T-2 indicates landfill temperatures greater than 120 degrees F occur in the landfill below 20 ft of the surface.

The temperature probe in T-3 from approximately 12 to 20 ft below the top of the probe may reflect the surface and subsurface combustion along the quarry wall. The rapid decrease in temperature below approximately 20 ft beneath the top of the probe indicates that the subsurface combustion is within 20 ft of the surface. The low concentrations of carbon monoxide in T-2 and T-3 also indicates that subsurface combustion in the refuse is limited (or non-existent), and is restricted to within 20 ft of the surface along the quarry wall. Carbon monoxide produced in the combustion may be venting through the surface cracks along the quarry wall.

RECOMMENDATIONS

Four steps should be taken to further mitigate the surface and subsurface combustion. These steps are as follows:

1. For the near term, maintain current conditions (i.e., maintain a sealed landfill surface, positive pressure conditions, and no LFG extraction in the immediate vicinity of the quarry wall and monitoring probes). TRW-1, TRW-2, and TRW-3 should remain shut off from header vacuum to maintain positive pressure conditions.

2. Inject a Portland cement slurry in the cracks along the quarry wall of the surface and subsurface combustion. The slurry must be thin so that it can penetrate and fill all cracks within 20 to 30 ft of the surface. The Portland cement slurry may be purchased from Redbird Concrete Company.

   Slurry would first be injected in cracks on either side of the surface and subsurface combustion to contain the combustion in the present location. Otherwise, the combustion could move laterally if initially injected directly into the area of combustion. The injection of slurry on the sides would also reduce the pathways of oxygen from the atmosphere and methane from the landfill feeding the combustion. Preventing oxygen from entering into the refuse mass is of paramount importance in suppressing the combustion. The slurry should be injected with high pressure pumps which could be provided by United Geosciences.

Injection of slurry into the area of combustion can proceed once the cracks on the two sides have been filled. Temperatures in the combustion may exceed 1,000 degrees F. All safety precautions should be taken including the wearing of protective clothing and safety glasses. The addition of bentonite to the slurry may be necessary to increase the thickness of the slurry. Injection of slurry should proceed until the combustion has terminated, and all cracks in the combustion area have been filled.

3. Line the areas along the quarry wall with bentonite. The areas of past and present surface and subsurface combustion should be lined. Other areas may be considered. All dirt and debris should be cleared from the quarry wall. A trench up to 2 ft deep should be excavated and filled with bentonite. A non-shrinking bentonite is preferred. The bentonite will remain in a semi-gel, and will settle along the quarry wall along with the landfill. Cracks along the quarry wall will be minimal since the bentonite should remain in a semi-gel stage.

4. Monitor T-1 through T-6 after mitigation for up to several weeks. TRW-1, TRW-2, and TRW-3 can be slowly opened to header vacuum once the temperatures in T-2 and T-3 reach an acceptable level. The landfill should be maintained under pressure to prevent air intrusion. T-1 through T-6 should be monitored and should maintain positive pressure.

SUMMARY

The infrared thermography of the site and the data from T-1 through T-6 both suggest that the surface and subsurface combustion is limited to the area along the quarry well in the vicinity of T-2 and T-3. There appears to be a hot mass consisting of dirt and possibly refuse approximately 10 to 20 ft below the surface along the quarry wall.

An injection of a Portland cement slurry in cracks on the sides of combustion and then into the combustion area is recommended. This will prevent the combustion from moving laterally and will plug the source of oxygen to the combustion area. Bentonite should be placed around the quarry wall to reduce air intrusion and possible future combustion. TRW-1, TRW-2, and TRW-3 can be operated once subsurface temperature in T-2 and T-3 are acceptable. A re-evaluation of the mitigation efforts can be performed at that time.

Please feel free to discuss our findings and recommendations with any of the undersigned.

Sincerely,

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Encl.

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