Landfills: Regulations, Design/Operations, Emissions and Inspection

Course 491

Student Workbook

Presented For CenSARA and Kansas DEP

May 21 - 23, 2024

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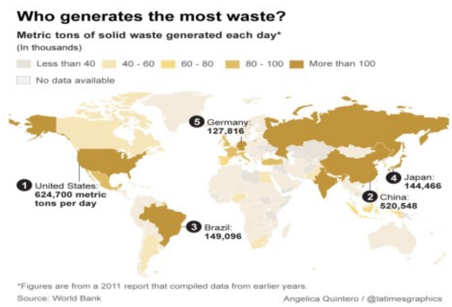
LA Times Article: The world's trash crisis, and why many Americans are oblivious By ANN M. SIMMONS APR 22, 2016



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https://www.latimes.com/world/global-development/la-fg-global-trash-20160422-20160421-snap-htmlstory.html

Waste Disposal Practices in the Past

- **3000 BC, Crete** – People dig deep holes to hide refuse which they would then cover with dirt.
- **500 BC, Athens, Greece** – The government develops a law requiring garbage to be dumped at least one mile from the city to preserve its beauty and prevent illness.
- **1354, England** – King Edward III implements rakers, or people who were hired to remove trash from the streets on a weekly basis. These rakers then bring the waste to the River Thames to dump it.

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Waste Disposal Practices in the Past

- **1388, England** – English Parliament bans dumping of waste in ditches and public waterways.
- **1400s, Paris** – The city struggles to maintain defense as garbage piles rises to monstrous heights directly outside of city walls.
- **1657, New Amsterdam (present-day New York)** – The city passes the first anti-littering law, making it illegal to throw or leave waste in the streets.
- **1757, Pennsylvania** – Benjamin Franklin starts first street cleaning service and encourages the public to dig pits in the earth to dispose of waste.

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Waste Disposal Practices in the Past

- **1842, England** – Social reformer Edwin Chadwick publishes *The Sanitary Condition of the Laboring Population*. The work is influential in securing the passage of the first legislation aimed at waste clearance and disposal. This work launches the Age of Sanitation.
- **1878, Tennessee** – The yellow fever epidemic ravages Memphis. In the aftermath, the city organizes garbage collection from homes and businesses using small wooden carts pulled by mules as part of an ambitious sanitary reform.
- **1885, New York** – The first garbage incinerator in America is built on Governor's Island, NY.

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History of Landfills (cont.)

- **From colonial times, residents of American cities tossed trash and garbage onto their streets. As cities grew, so did the volumes of garbage. Modern solid waste management started in 1895, when New York City Street Cleaning Commissioner Colonel George E. Waring Jr. arranged to send the city's wastes to dumps and incinerators, or to be deposited in waterways. The New York Board of Health quickly noticed that this new policy lowered the city's death rate from disease, one indication of the problems caused by waste. Most cities at that time still had no organized system of disposal, continuing to pile rubbish in open pits that could catch on fire or be set on fire intentionally.**

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History of Sanitary Landfills

It is not clear as to when burying refuse became an idea. Some say that the first written description of the sanitary landfill concept can be found in the Bible (Deuteronomy 23:14). Literature dating back to 1929 includes an article on garbage disposal by "sanitary fill" which was referring to burying the waste. This was a big improvement over open dumps which persisted into the 20th Century.

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A Garbage Timeline Website

- [INFOGRAPHIC: A History of Waste Disposal in the United States (sharpsinc.com)]

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Landfilling and Garbage Dumping in 1908

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Refuse Collection in the 1920's

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Dumping Waste At Sea In New York Harbor, a Common Practice In 1880s.

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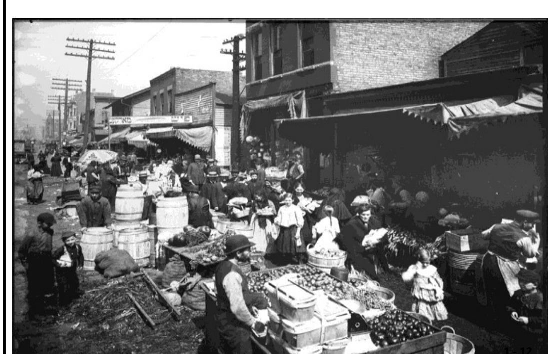
Chicago Maxwell Street 1915



The Jungle by Upton Sinclair 1908

In the northwestern corner of the neighborhood, the city was filling in low, swampy lands and clay pits by dumping garbage. The garbage attracted flies, rats, and human scavengers from the neighborhood. Sinclair writes: "Here was a great hole, perhaps two city blocks square, and with long files of garbage wagons creeping into it. The place had an odor for which there are no polite words; and it was sprinkled over with children, who raked in it from dawn till dark. Sometimes visitors from the packing houses would wander out to see this `dump,' and they would stand by and debate as to whether the children were eating the food they got, or merely collecting it for the chickens at home."

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"The Jungle" by Upton Sinclair 1908

Some parts of the neighborhood were built on landfill. Sinclair writes: "The roadway was commonly several feet lower than the level of the houses, which were sometimes joined by high board walks; there were no pavements--there were mountains and valleys and rivers, gullies and ditches, and great hollows full of stinking green water. In these pools the children played, and rolled about in the mud of the streets; here and there one noticed them digging in it, after trophies which they had stumbled on. One wondered about this, as also about the swarms of flies which hung about the scene, literally blackening the air, and the strange, fetid odor which assailed one's nostrils, a ghastly odor, of all the dead things of the universe. It impelled the visitor to questions and then the residents would explain, quietly, that all this was `made' land, and that it had been `made' by using it as a dumping ground for the city garbage. After a few years the unpleasant effect of this would pass away, it was said; but meantime, in hot weather--and especially when it rained--the flies were apt to be annoying. Was it not unhealthful? The stranger would ask, and the residents would answer, `Perhaps; but there is no telling.'"

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TYPICAL RESIDENCE STREET "BACK OF THE YARDS."

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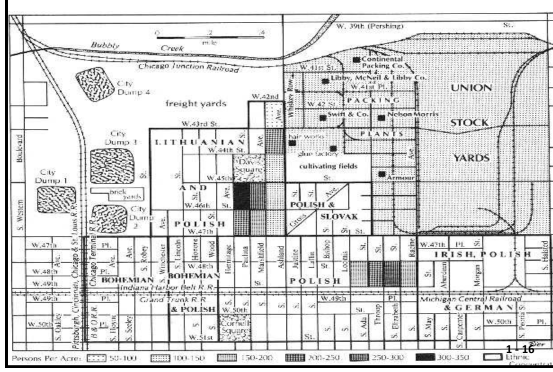
"Back of the Yards" Neighborhoods



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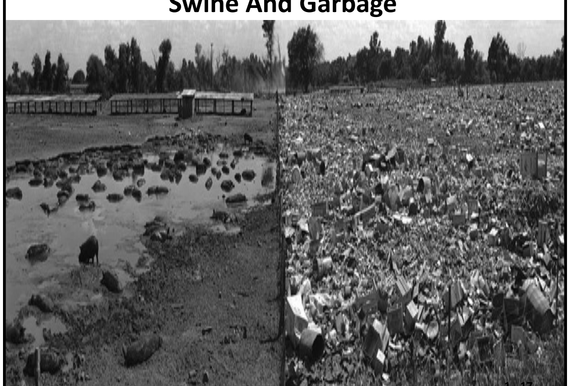
Swine And Garbage



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Garbage Fed to Animals and Disease

- Trichinella spiralis, first noted to be pathogenic for humans in 1859, remains a public health problem in the United States. Infection occurs when raw or inadequately cooked meat, most commonly pork, is ingested. Of cases reported during 1975-1981, where an infected meat item was identified, pork was implicated in 79.1%; wild meat, in 13.9%; and ground beef, in 7.0%. The incriminated ground beef was believed to have been adulterated by pork products.

http://www.cdc.gov/mmwr/preview/mmwrhtml/00000404.htm

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Landfilling in the 1940's

- An example of a landfill of the late 1940s was described in a report prepared by the Sanitary Engineering Research Project of the University of California in 1952. The landfill studied in 1949 was described as follows: "Refuse was dropped and spread out over a large area to allow scavengers easy access. At the end of the day pigs were allowed on the spread-out refuse for overnight feeding. The next day the pigs were herded off and the refuse was pushed to the edge of the fill for burning."

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Sanitary Landfill Facts US DPH Publication 1970 Cover

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Brief History of Solid Waste Management in the US, 1950-2000

Timeline of waste management - Timelines (issarice.com)

http://environmentalchemistry.com/yogi/environmental/wastehistory.html

Books on this subject

Gone Tomorrow: The Hidden Life of Garbage
by Heather Rogers

American alchemy: The history of solid waste management in the United States by H. Lanier Hickman Jr.

Rubbish: The Archaeology of Garbage
What Our Garbage Tells Us About Ourselves
by William Rathje & Cullen Murphy

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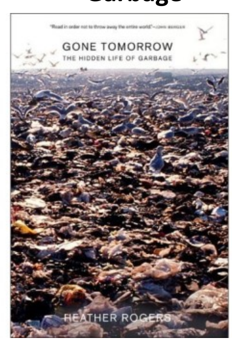
Gone Tomorrow: The Hidden Life of Garbage



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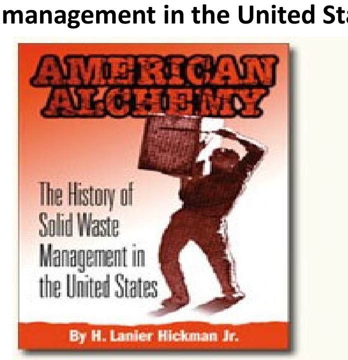
American alchemy: The history of solid waste management in the United States



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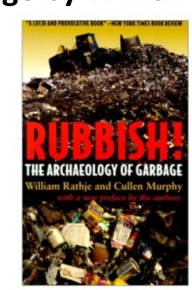
Rubbish!: The Archaeology of Garbage by William Rathje



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Separation of household waste

"It is commonly the practice in American towns to make a separation in the household of three classes of waste….

The householder is required to have three receptacles, for garbage, ashes and rubbish"

William F. Morse, "The Disposal of the City's Waste" American City 2 no. 4

April 1910, p 180

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Sanitary Landfill

- **The "sanitary landfill",** which the British began, by covering the trash each day with earth in the 1920's, was the breakthrough that ultimately elevated the practice of filling to the status of primary disposal option in the United States. However, it did not come into substantial use until after World War II, stimulated in large measure by the success of the Fresno Sanitary Landfill (FSL) and the work of its originator**,** Jean Vincenz.

http://historicfresno.org/nrhp/landfill.htm

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Fresno Sanitary Landfill as a National Historic Landmark

- **On August 27, 2001, Department of Interior designated the Fresno Sanitary Landfill as a National Historic Landmark. The next day, Secretary Gail Norton "temporarily" rescinded the designation, claiming that the department was not aware of the landfill's Superfund status. For many people, the naming of a landfill as an historic landmark seemed ludicrous. For others, the designation offered an opportunity to pillory the Bush administration for its increasingly unpopular environmental policies. What got lost sight of was why the nomination was made in the first place, and if it had any merit as a historically significant site. The controversy also exposed the inability of people to take the waste issue seriously, to view it as an integral part of the process of living, and thus to conceive it as culturally and historically important.**

The Fresno Sanitary Landfill in an American Cultural Context by Martin V. Melosi The Public Historian Summer 2002, Vol. 24, No. 3, Pages 17–35

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Ugh!

What in the world is causing the big stink in Hillside?

By Brett McNeil
Tribune staff reporter

Published April 9, 2006

Joe Tamburino struggles for words when trying to describe the fetid, gaseous stench from a local landfill that for more than five months has hung over Hillside and wafted across other western suburbs.

"It's the worst odor I've ever smelled. I've smelled dead bodies--I spent a year in Vietnam--and this is worse," says Tamburino, Hillside's village president. "Once this gets in your home, it gets in your clothes. You can't open your window to get rid of the odor because it's worse outside."

It's also illegal, according to court papers. Under federal, state and local laws, landfills are required to collect and destroy gases that are the natural byproduct of decomposing waste in landfills.

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States with the Most Landfill Waste | Stacker

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Municipal Solid Waste Information, Generation, Landfill Construction and Microbial Action

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Basic Landfill Information

- Modern landfills are engineered and managed facilities for the disposal of solid waste. Landfills are located, designed, operated and monitored to ensure compliance with federal regulations. Landfills should not be built in environmentally-sensitive areas, and they are required to have on-site environmental monitoring systems. These monitoring systems check for any sign of groundwater contamination and for landfill gas. Today's landfills must meet stringent design, operation and closure requirements established under the Resource Conservation and Recovery Act (RCRA).

1B - 2

Types of Regulated Landfills

- Landfills are regulated under RCRA Subtitle D (solid waste) and Subtitle C (hazardous waste) or under the Toxic Substances Control Act (TSCA).
- Subtitle D focuses on state and local governments as the primary planning, regulating and implementing entities for the management of nonhazardous solid waste, such as household garbage and nonhazardous industrial solid waste. Subtitle D landfills include the following:
- Municipal Solid Waste Landfills (MSWLFs) – Specifically designed to receive household waste, as well as other types of nonhazardous wastes.
  - Bioreactor Landfills – A type of MSWLF that operates to rapidly transform and degrade organic waste.

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Types of Regulated Landfills

- Industrial Waste Landfill – Designed to collect commercial and institutional waste (i.e. industrial waste), which is often a significant portion of solid waste, even in small cities and suburbs.
  - Construction and Demolition (C&D) Debris Landfill – A type of industrial waste landfill designed exclusively for construction and demolition materials, which consists of the debris generated during the construction, renovation and demolition of buildings, roads and bridges. C&D materials often contain bulky, heavy materials, such as concrete, wood, metals, glass and salvaged building components.
  - Coal Combustion Residual (CCR) landfills – An industrial waste landfill used to manage and dispose of coal combustion residuals (CCRs or coal ash). EPA established requirements for the disposal of CCR in landfills and published them in the Federal Register April 17, 2015.

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Types of Regulated Landfills

- Subtitle C establishes a federal program to manage hazardous wastes from cradle to grave. The objective of the Subtitle C program is to ensure that hazardous waste is handled in a manner that protects human health and the environment. To this end, there are Subtitle C regulations for the generation, transportation and treatment, storage or disposal of hazardous wastes. Subtitle C landfills including the following:
- Hazardous Waste Landfills - Facilities used specifically for the disposal of hazardous waste. These landfills are not used for the disposal of solid waste.
- Polychlorinated Biphenyl (PCB) landfills - PCBs are regulated by the Toxic Substances Control Act. While many PCB decontamination processes do not require EPA approval, some do require approval.

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https://www.epa.gov/sites/production/files/2020-11/documents/2018_facts_and_figures_fact_sheet_final.pdf

1B - 6

Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2017

In 2015, Americans generated about 268 million tons of trash and recycled 67 million tons of materials and 27 million tons were composted, which is 34 percent. (See Figure 1 and Figure 2.) In addition, more than 34 million tons of MSW (12.7 percent) were combusted with energy recovery. Finally, more than 139 million tons of MSW (52.1 percent) were landfilled (*See* Figure 3 and Table 1).

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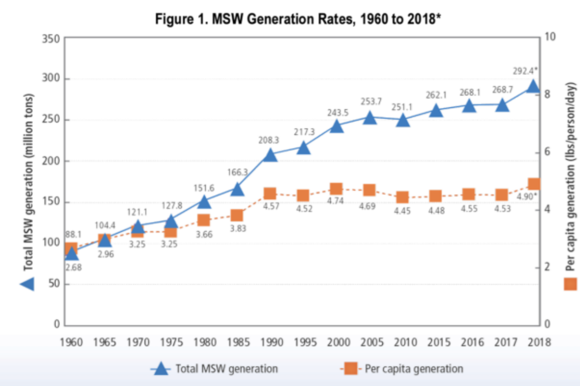

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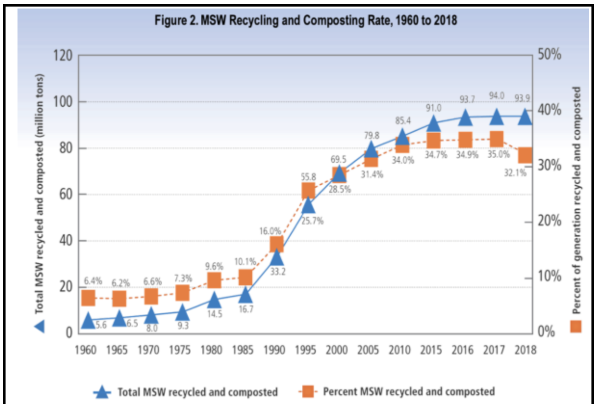

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Table 1. Generation, Recycling, Composting, Other Food Management Pathways, Combustion with Energy Recovery and Landfilling of Materials in MSW, 2018*
(in millions of tons and percent of generation of each material)

Material	Weight Generated	Weight Recycled	Weight Composted	Weight Other Food Management Pathways¥	Weight Combusted with Energy Recovery	Weight Landfilled	Recycling as Percent of Generation	Composting as Percent of Generation	Other Food Management Pathways as Percent of Generation	Combustion as Percent of Generation	Landfilling as Percent of Generation
Paper and paperboard	67.39	45.97	-	-	4.20	17.22	68.2%	-	-	6.2%	25.6%
Glass	12.25	3.06	-	-	1.64	7.55	25.0%	-	-	13.4%	61.6%
Metals											
Steel	19.20	6.36	-	-	2.31	10.53	33.1%	-	-	12.0%	54.9%
Aluminum	3.89	0.67	-	-	0.56	2.66	17.2%	-	-	14.4%	68.4%
Other nonferrous metals†	2.51	1.69	-	-	0.08	0.74	67.3%	-	-	3.2%	29.5%
Total metals	**25.60**	**8.72**	-	-	**2.95**	**13.93**	**34.1%**	-	-	**11.5%**	**54.4%**
Plastics	35.68	3.09	-	-	5.62	26.97	8.7%	-	-	15.8%	75.5%
Rubber and leather	9.16	1.67	-	-	2.50	4.99	18.2%	-	-	27.3%	54.5%
Textiles	17.03	2.51	-	-	3.22	11.30	14.7%	-	-	18.9%	66.4%
Wood	18.09	3.10	-	-	2.84	12.15	17.1%	-	-	15.7%	67.2%
Other materials	4.56	0.97	-	-	0.66	2.93	21.3%	-	-	14.4%	64.3%
Total materials in products	**189.76**	**69.09**	-	-	**23.63**	**97.04**	**36.4%**	-	-	**12.5%**	**51.1%**
Other wastes											
Food, other‡	63.13	-	2.59	17.71	7.55	35.28	-	4.1%	28.1%	11.9%	55.9%
Yard trimmings	35.40	-	22.30	-	2.57	10.53	-	63.0%	-	7.3%	29.7%
Miscellaneous inorganic wastes	4.07	-	-	-	0.80	3.27	-	-	-	19.7%	80.3%
Total other wastes	**102.60**	-	**24.89**	**17.71**	**10.92**	**49.08**	-	**24.3%**	**17.3%**	**10.6%**	**47.8%**
Total municipal solid waste	**292.36**	**69.09**	**24.89**	**17.71**	**34.55**	**146.12**	**23.6%**	**8.5%**	**6.1%**	**11.8%**	**50.0%**

* Includes waste from residential, commercial and institutional sources.
¥ Animal feed, bio-based materials/biochemical processing, codigestion/anaerobic digestion, donation, land application, sewer/wastewater treatment.
† Includes lead from lead-acid batteries.
‡ Includes collection of other MSW organics for composting.

Details might not add to totals due to rounding.
Negligible = Less than 5,000 tons or 0.05 percent.
A dash in the table means that data are not available.

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Table 2. Generation, Recycling, Composting, Other Food Management Pathways, Combustion with Energy Recovery and Landfilling of MSW, 1960 to 2018 (in millions of tons)

Activity	1960	1970	1980	1990	2000	2005	2010	2015	2017	2018
Generation	88.1	121.1	151.6	208.3	243.5	253.7	251.1	262.1	268.7	292.4
Recycling	5.6	8.0	14.5	29.0	53.0	59.2	65.3	67.6	67.0	69.1
Composting*	neg.	neg.	neg.	4.2	16.5	20.6	20.2	23.4	27.0	24.9
Other Food Management**	-	-	-	-	-	-	-	-	-	17.7
Combustion with energy recovery†	0.0	0.5	2.8	29.8	33.7	31.7	29.3	33.5	34.2	34.6
Landfilling and other disposal‡	82.5	112.6	134.3	145.3	140.3	142.2	136.3	137.6	140.5	146.1

* Composting of yard trimmings, food and other MSW organic material. Does not include backyard composting.
** Other food management pathways include animal feed, bio-based materials/biochemical processing, codigestion/anaerobic digestion, donation, land application and sewer/wastewater treatment.

Details might not add to totals due to rounding.
neg. (negligible) = less than 5,000 tons or 0.05 percent.
A dash in the table means that data are not available.

† Includes combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g., wood pallets, tire-derived fuel).
‡ Landfilling is what remains after recycling, composting, other food management and combustion with energy recovery are accounted for. Landfilling includes other disposal methods such as combustion without energy recovery.

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Management of MSW in the United States, 2017

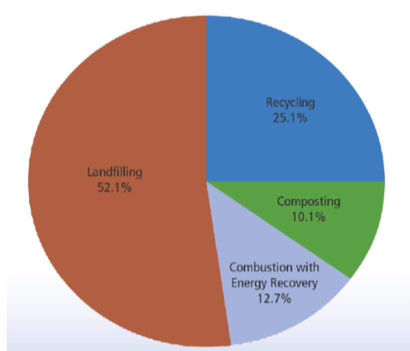

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Table 3. Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling of MSW, 1960 to 2017 (in pounds per person per day)

Activity	1960	1970	1980	1990	2000	2005	2010	2015	2016	2017
Generation	2.7	3.3	3.7	4.6	4.7	4.7	4.4	4.5	4.5	4.5
Recycling	0.2	0.2	0.4	0.6	1.0	1.1	1.1	1.2	1.2	1.1
Composting*	neg.	neg.	neg.	0.1	0.3	0.4	0.4	0.4	0.4	0.5
Combustion with energy recovery†	0.0	neg.	0.1	0.7	0.7	0.6	0.5	0.6	0.6	0.6
Landfilling and other disposal‡	2.5	3.1	3.2	3.2	2.7	2.6	2.4	2.3	2.3	2.3
Population (In millions)	180.0	204.0	227.3	249.9	281.4	296.4	309.1	320.9	323.1	325.1

* Composting of yard trimmings, food, and other MSW organic material. Does not include backyard composting.

† Includes combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g., wood pallets, tire-derived fuel).

‡ Landfilling after recycling, composting, and combustion with energy recovery. Includes combustion without energy recovery.

Details might not add to totals due to rounding.
neg. (negligible) = less than 5,000 tons.

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Table 4. Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling of Products in MSW, 2017*
(in millions of tons and percent of generation of each product)

Products	Weight Generated	Weight Recycled	Weight Composted	Weight Combusted with Energy Recovery	Weight Landfilled	Recycling as Percent of Generation	Composting as Percent of Generation	Combustion as Percent of Generation	Landfilling as Percent of Generation
Durable goods									
Steel	16.88	4.70	-	2.19	9.99	27.8%	-	13.0%	59.2%
Aluminum	1.72	-	-	0.26	1.46	-	-	15.1%	84.9%
Other nonferrous metals†	2.33	1.54	-	0.07	0.72	66.1%	-	3.0%	30.9%
Glass	2.45	Negligible	-	0.32	2.13	Negligible	-	13.1%	86.9%
Plastics	13.46	0.85	-	1.72	10.89	6.3%	-	12.8%	80.9%
Rubber and leather	7.94	1.67	-	2.27	4.00	21.0%	-	28.6%	50.4%
Wood	6.59	Negligible	-	1.20	5.39	Negligible	-	18.2%	81.8%
Textiles	3.91	0.59	-	1.02	2.30	15.1%	-	26.1%	58.8%
Other materials	1.84	1.45	-	0.03	0.36	78.8%	-	1.6%	19.6%
Total durable goods	**57.12**	**10.80**	**-**	**9.08**	**37.24**	**18.9%**	**-**	**15.9%**	**65.2%**
Nondurable goods									
Paper and paperboard	25.95	14.09	-	2.33	9.53	54.3%	-	9.0%	36.7%
Plastics	7.42	0.22	-	1.40	5.80	3.0%	-	18.9%	78.2%
Rubber and leather	1.17	Negligible	-	0.22	0.95	Negligible	-	18.8%	81.2%
Textiles	12.68	1.98	-	2.09	8.61	15.6%	-	16.5%	67.9%
Other materials	3.48	Negligible	-	0.68	2.80	Negligible	-	19.5%	80.5%
Total nondurable goods	**50.70**	**16.29**	**-**	**6.72**	**27.69**	**32.1%**	**-**	**13.3%**	**54.6%**

Table 4 (continued). Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling of Products in MSW, 2017*
(in millions of tons and percent of generation of each product)

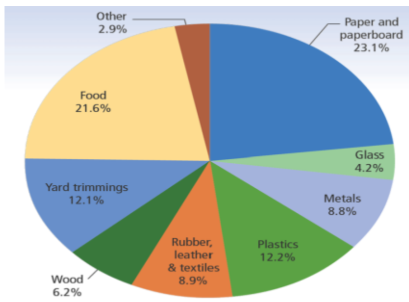
Products	Weight Generated	Weight Recycled	Weight Composted	Weight Combusted with Energy Recovery	Weight Landfilled	Recycling as Percent of Generation	Composting as Percent of Generation	Combustion as Percent of Generation	Landfilling as Percent of Generation
Containers and packaging									
Steel	2.01	1.47	-	0.10	0.44	73.1%	-	5.0%	21.9%
Aluminum	1.89	0.62	-	0.26	1.01	32.8%	-	13.8%	53.4%
Glass	8.93	3.03	-	1.16	4.74	33.9%	-	13.0%	53.1%
Paper and paperboard	41.06	30.08	-	2.16	8.82	73.3%	-	5.3%	21.5%
Plastics	14.49	1.89	-	2.47	10.13	13.0%	-	17.0%	69.9%
Wood	11.40	3.00	-	1.65	6.75	26.3%	-	14.5%	59.2%
Other materials	0.30	Negligible	-	0.06	0.24	Negligible	-	20.0%	80.0%
Total containers and packaging	**80.08**	**40.09**	**-**	**7.86**	**32.13**	**50.1%**	**-**	**9.8%**	**40.1%**
Other wastes									
Food, other‡	40.67	-	2.57	7.47	30.63	-	6.3%	18.4%	75.3%
Yard trimmings	35.18	-	24.42	2.11	8.65	-	69.4%	6.0%	24.6%
Miscellaneous inorganic wastes	4.04	-	-	0.79	3.25	-	-	19.6%	80.4%
Total other wastes	**79.89**	**-**	**26.99**	**10.37**	**42.53**	**-**	**33.8%**	**13.0%**	**53.2%**
Total municipal solid waste	**267.79**	**67.18**	**26.99**	**34.03**	**139.59**	**25.1%**	**10.1%**	**12.7%**	**52.1%**

* Includes waste from residential, commercial and institutional sources.
† Includes lead from lead-acid batteries.
‡ Includes collection of other MSW organics for composting.

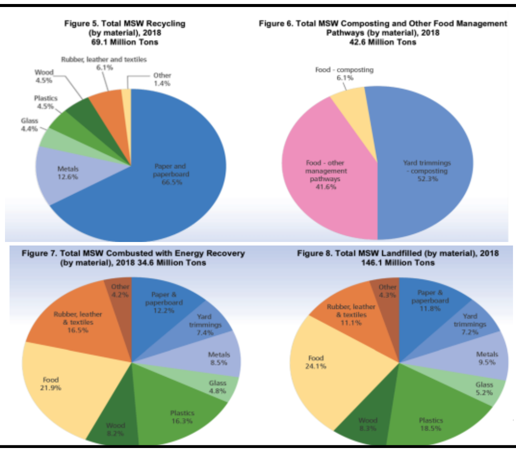
Details might not add to totals due to rounding.
Negligible = less than 5,000 tons or 0.05 percent.
A dash in the table means that data are not available.

1B - 15

Total MSW Generation (by Category), 2018
292.4 Million Tons (Before Recycling)



1B - 16



- 17

Are Our Recyclables Being Recycled?

Recycling in the U.S. Is Broken. How Do We Fix It? (columbia.edu)

1B - 18

https://smea.uw.edu/about/student-blog/blog/wishful-recycling-more-harm-than-good/

More Information

- Information on the benefits of recycling, such as elimination of greenhouse gas (GHG) emissions, comes from EPA's WAste Reduction Model (WARM). WARM calculates and totals GHG emissions of baseline and alternative waste management practices—source reduction, recycling, composting, combustion, and landfilling. The model calculates emissions in metric tons of carbon equivalent (MTCE), metric tons of carbon dioxide equivalent (MTCO2E), and energy units (million BTUs) across a wide range of material types commonly found in MSW. EPA developed GHG emissions reduction factors through a life-cycle assessment methodology. EPA's report, ***Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*** (EPA 530-R-02-006), describes this methodology in detail

Solid Waste Management and Greenhouse Gases: A Life ... https://nepis.epa.gov › Exe › ZyPURL

1B - 19

More Information

https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling

https://www.epa.gov/hw/criteria-definition-solid-waste-and-solid-and-hazardous-waste-exclusions

1B - 20

- **The number of landfills in the United States is declining, yet the amount of waste generated is increasing.**
- **Surveys of U.S. landfills have shown a steady decline in the estimated number of landfills taking MSW with 6,034 landfills in 1986, 3,558 landfills in 1994 3,216 in 1999 and 3091 in 2019 (EPA, 1988; Steuteville, 2000).**
- **There are also about 10,000 old municipal landfills.**

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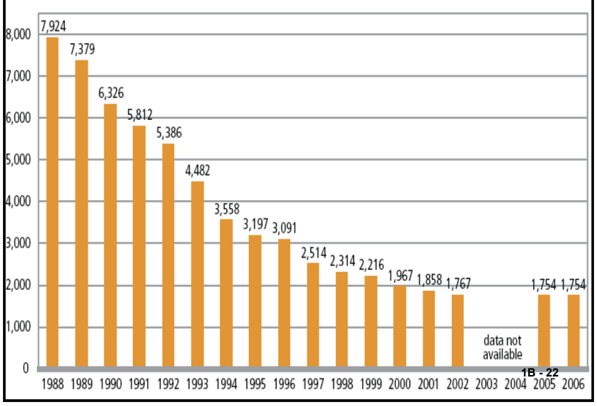
Number of Landfills in the United States, 1988–2006



1B - 22

Municipal Solid Waste Landfills

A municipal solid waste (MSW) landfill unit is a discrete area of land or an excavation that receives household waste, and that is not a land application unit, surface impoundment, injection well, or waste pile.

An MSW landfill unit may also receive other types of wastes, such as commercial solid waste, non-hazardous sludge, and industrial solid waste.

The municipal solid waste types potentially accepted by MSW landfills include (most landfills accept only a few of the following categories):

- MSW,
- Household hazardous waste,
- Municipal sludge,
- Municipal waste combustion ash,
- Infectious waste,
- Waste tires,
- Industrial non-hazardous waste,
- Conditionally exempt small quantity generator (CESQG) hazardous waste,
- Construction and demolition waste,
- Agricultural wastes,
- Oil and gas wastes, and
- Mining wastes

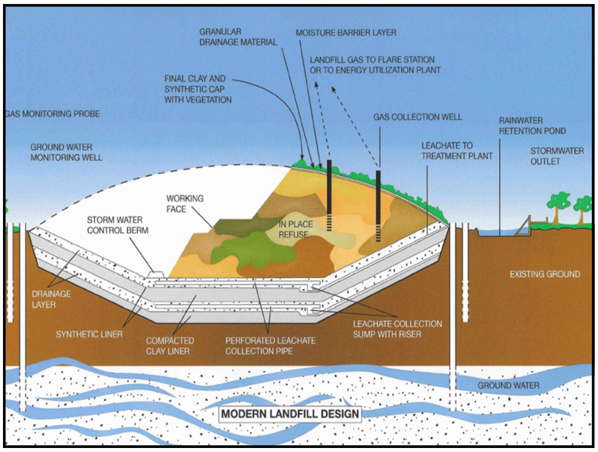
1B - 23

Municipal Solid Waste Landfills (MSWLFs)

In general, a MSWLF is a landfill that accepts garbage, or solid waste, from households. Wastes that are typically land filled include bottles, cans, disposable diapers, uneaten food, scraps of wood and metal, newspapers, paper and plastic packaging, and old appliances, as well as some industrial and commercial non-hazardous wastes and construction and demolition (C&D) wastes.

MSWLFs may also accept household hazardous wastes and conditionally exempt small quantity generator (CESQG) wastes that are not regulated as hazardous wastes under Subtitle C of the Resource Conservation and Recovery Act (RCRA).

1B - 24



Municipal Solid Waste Landfills (MSWLFs)

The MSWLF regulations promulgated on October 9, 1991 addresses location restrictions, facility design and operation standards, groundwater monitoring and corrective action measures, closure and post-closure care, and financial responsibility requirements (56 FR 50978).

Implementation of these regulations, by states with approved programs, will reduce the environmental impact of existing and future MSWLFs

1B - 26

Landfill Subtitle D Regulations

RCRA Subtitle D addresses solid waste management and was designed to assist waste management officials in developing and encouraging environmentally sound methods for the disposal of "non-hazardous" solid waste (RCRA §4001).

Promulgated under the authority of Subtitle D, the MSWLF regulations in Part 258 establish a framework at the federal level for planning and implementing municipal solid waste landfill programs at the state and local levels.

This framework sets minimum standards for protecting human health and the environment, while allowing states to develop more flexible MSWLF criteria.

Current regulations require leachate and LFG emissions to be monitored for at least 30 years after closure of a landfill site or as long as environmental risk are present.

1B - 27

EXPLOSIVE GASES CONTROL

The decomposition of organic waste produces methane gas. High concentrations of methane in MSWLF structures or the facility area create an explosion hazard for employees, facility users, and occupants of nearby structures. To mitigate potential hazards, a routine methane monitoring program, conducted at least quarterly, must be implemented in accordance with §258.23(b) to ensure that the following conditions are maintained:

- In facility structures, the concentration of methane gas must not exceed 25 percent of the lower explosive limit for methane as defined I §258.23(d)
- At the facility property boundary, the concentration of methane gas must not exceed the lower explosive limit. While §258.23(c) outlines the procedures that the owner and operator must follow if these methane levels are exceeded, states with approved programs may establish alternative response procedures (§258.23(c)(4)).

1B - 28

Air Criteria Under Subtitle D

In general, air emissions from MSWLFs are regulated under the Clean Air Act (CAA), not under RCRA (56 FR 51053; October 9, 1991). Nevertheless, §258.24 prohibits open burning of nearly all solid wastes at MSWLFs; only the infrequent burning of agricultural wastes, silvicultural (forestry) wastes, land-cleaning debris, diseased trees, and debris from emergency cleanup operations is permitted (§258.24(b)). Additionally, landfill gas performance standards for new landfills and guidelines for existing landfills were promulgated under the authority of the CAA on March 12, 1996 (61 FR 9905). EPA published on January 16, 2003 (68 FR 2227), the National Emission Standards for Hazardous Air Pollutants (NESHAPS) for MSWLFs.

1B - 29

EXPLOSIONS AND FIRES AT DUMPS (LANDFILLS) (Internet)

- According to the U.S. Fire Administration, there are fires at 8,300 dumps each year.
- Heat from decaying trash can ignite the gases within a dump, resulting in fires that can spread underground for miles.
- FLORIDA Orlando

  1998 . The Walt Disney World construction landfill, where asbestos is buried, catches fire. Two nearby golf courses are closed because officials fear the smoke might be contaminated.

1B - 30

EXPLOSIONS AND FIRES AT DUMPS (LANDFILLS) (Internet)

- **ILLINOIS Naperville (Chicago suburb)**

  2004 . Fires from spontaneous combustion burn in the dump beneath the Greene Valley Forest Preserve. A grass fire that erupted on the surface had been extinguished, but the underground fires continue for months.
- **INDIANA Wabash**

  1987 - People are forced to evacuate their homes and businesses when a fire erupts at a nearby toxic waste dump.

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ATSDR LFG Web Site

http://www.atsdr.cdc.gov/HAC/landfill/html/appe.html#1

1B - 32

Description of Landfill Operations

- **There are three major designs for municipal landfills. These are the area, trench, and ramp methods.**
- **These methods utilize a three step process, which includes spreading the waste, compacting the waste, and covering the waste with soil.**
- **The trench and ramp methods are not commonly used, and are not the preferred methods when liners and leachate collection systems are utilized or required by law.**

1B - 33

Description of Landfill Operations

- **The ramp method is typically employed on sloping land, where waste is spread and compacted similar to the area method, however, the cover material obtained is generally from the front of the working face of the filling operation.**
- **The trench method entails excavating trenches designed to receive a day's worth of waste. The soil from the excavation is often used for cover material and wind breaks.**
- **The area fill method involves placing waste on the ground surface or landfill liner, spreading it in layers, and compacting with heavy equipment.**

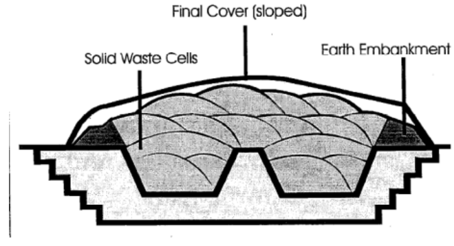
1B - 34

Excavated Cell/Trench Landfill

- **Generally, solid waste is placed in "cells" or trenches excavated in the soil and the excavated soil is used as daily and final cover, as shown in the following figure.**
- **Excavated square cells are usually up to 1000 feet in width and length.**
- **Trenches vary from~200 to 1000 feet in length, 10 to 30 feet in depth and 15 to 50 feet in width.**
- **In order to prevent subsurface gas migration and leachate leakage into the water table, the trenches are usually lined or have soils with low-permeability clay, or both.**

1B - 35

Excavated Cell/Trench Landfill



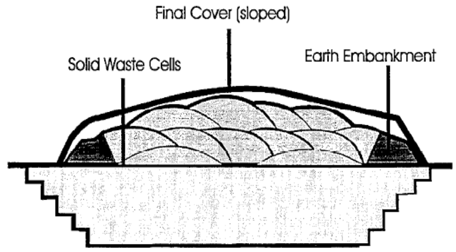
1B - 36

Mound Type Landfills

- Mound type landfills, as shown in the following figure are seen in areas of high groundwater or where terrain makes excavation difficult.
- Therefore, cover material must be imported from nearby areas or borrow-pits.
- Due to the large surface area, the potential for air intrusion is increased, and this in turn may increase surface emissions to the atmosphere.

1B - 37

Mound Type Landfills



1B - 38

Canyon and Ravine Landfills

The way refuse is dispersed in canyon and ravine landfills (see following figure) depends on site geometry, hydrology, geology, and access.

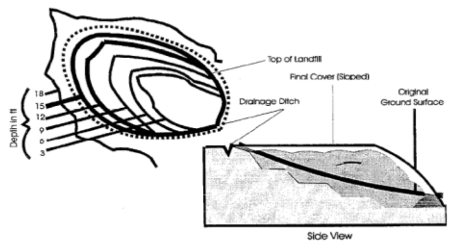
Cover material can be excavated from the canyon wall or bottom prior to filling.

Intermediate (daily) cover often has to be derived from adjacent areas or borrow pits.

This type of landfill typically has a greater depth of refuse than most other and fill types, which may result in increased settlement, causing fissures at the natural refuse interface and a higher potential for air intrusion and surface emissions.

1B - 39

Canyon and Ravine Landfills



1B - 40

Pit and Quarry Landfill

Pits and quarries are depressions that result from the removal of native material. Often, gravel quarries are located in alluvial deposits that consist of loose, permeable gravels.

Due to a low-surface-area-to mass ratio, the potential of surface emissions may be lower than other landfill types, but the potential of subsurface lateral migration can be greater. Deep depressions filled with refuse often result in a greater potential for settlement, especially at the refuse/natural material interface.

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Ameron Quarry as potential Oahu's Hawaii new landfill

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Landfill Liners

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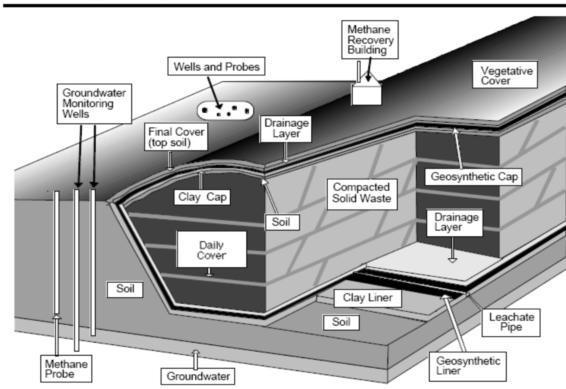
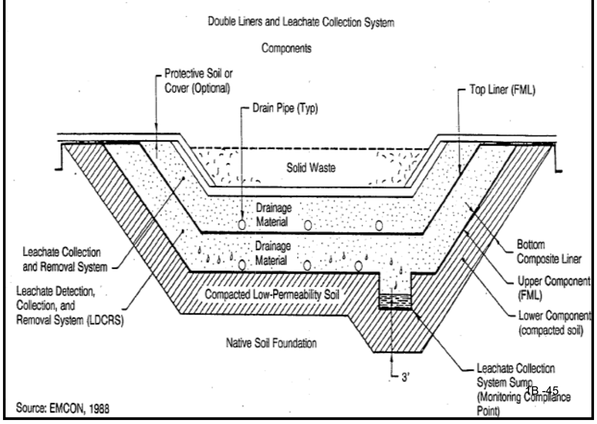
Landfill Liner Installation Steps (senecalandfill.com)

Schematic of a Typical Municipal Solid Waste Landfill



1B - 44

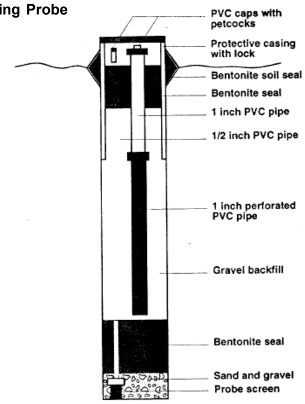
Source: P. O'Leary and P. Walsh, University of Wisconsin–Madison Solid and Hazardous Waste Education Center, reprinted from *Waste Age* 1991-1992



Source: EMCON, 1988

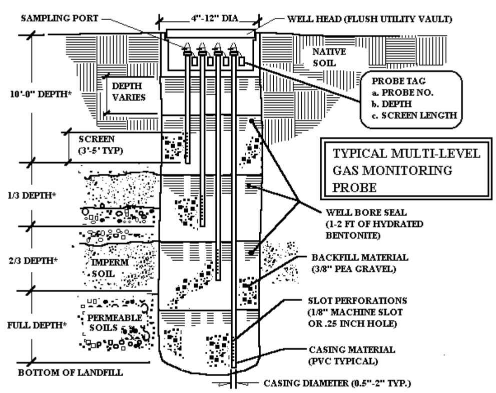
1B - 45

Typical Gas Monitoring Probe



Source: Warzyn Inc.

1B - 46

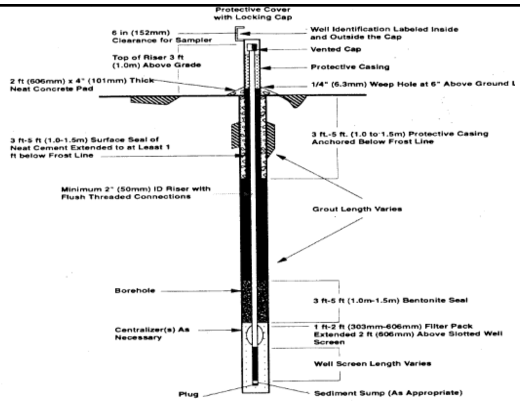


1B - 47

Example of a Multi-Depth Cluster Well.

Groundwater monitoring well system: Wells placed at an appropriate location and depth for taking water samples that are representative of groundwater quality.

1B - 48



Example of a Monitoring Well Design-Single Cased Well

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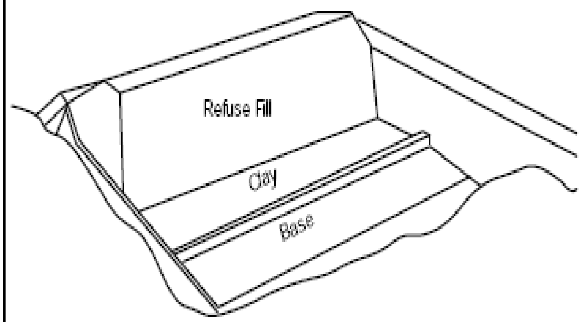
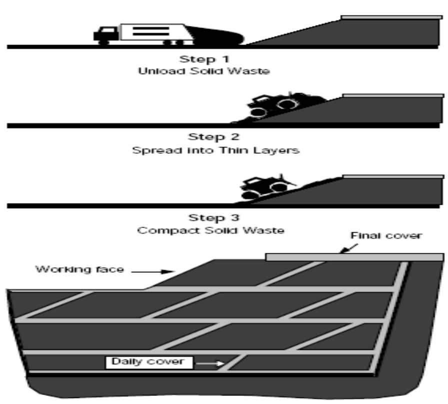
Landfill Construction Plan: Intermediate Phase



Source: P. O'Leary and P. Walsh, University of Wisconsin-Madison Solid and Hazardous Waste Education Center, reprinted from Waste Age Correspondence Course 1991-1992

1B - 50

Solid Waste Placement and Compaction



Completed Landfill Cells

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The McCommas Bluff Landfill, Operated by the City of Dallas

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New Bioreactor Area

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Leachate Injection Pipes

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Bioreactor Landfill Information

A bioreactor landfill operates to rapidly transform and degrade organic waste. The increase in waste degradation and stabilization is accomplished through the addition of liquid and air to enhance microbial processes.

This bioreactor concept differs from the traditional "dry tomb" municipal landfill approach.

A bioreactor landfill is not just a single design and will correspond to the operational process invoked. There are three different general types of bioreactor landfill configurations:

1B - 55

Landfill Chemistry and Microbiology

Morton A. Barlaz
Department of Civil Engineering
North Carolina State University

https://archive.epa.gov/epawaste/nonhaz/municipal/web/pdf/barlaz.pdf

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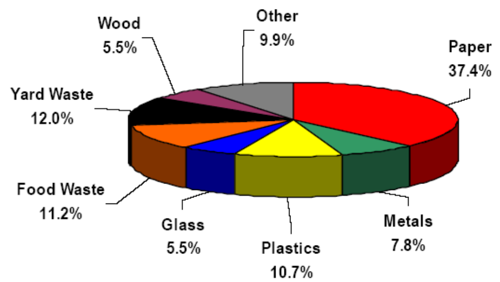
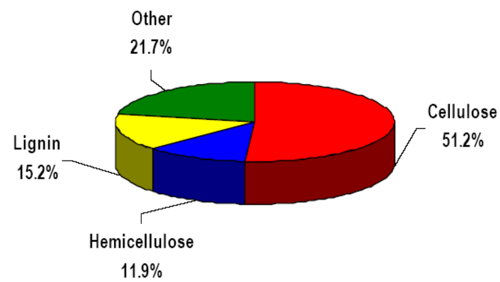
Refuse Composition

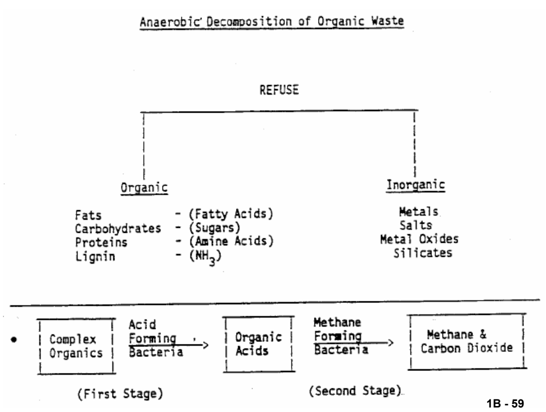


1B - 57

Refuse Composition



1B - 58



1B - 59

Microbiological Processes

I. Polymer Hydrolysis ⟶ soluble sugars, amino acids

cellulose
hemicellulose
proteins

For example,

$(C_6H_{10}O_5)_n + H_2O \rightarrow C_6H_{12}O_6 + (C_6H_{10}O_5)_{n-1}$

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Refuse Decomposition

Cellulose:

$(C_6H_{10}O_5)_n + nH_2O \rightarrow 3n\ CO_2 + 3n\ CH_4$

Hemicellulose:

$(C_5H_8O_4)_n + nH_2O \rightarrow 2.5n\ CO_2 + 2.5n\ CH_4$

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Example Chemical Pathway

- 1) Carbohydrates $\longrightarrow C_6H_{12}O_6$ (Sugar)

- $C_6H_{12}O_6 \xrightarrow{\text{Fermentation}} 2\ CO_2 + 2C_2H_5OH$ (Ethyl Alcohol)
- $2C_2H_5OH + H_2O \longrightarrow CH_5COOH$ (Acetate) $+ H_2$
-
- $CH_5COOH \xrightarrow{\text{Decarboxylation}} CH_4$ (Methane) $+ CO_2$ (Carbon Dioxide)

1B - 62

Microbiological Processes

- Methane Production
- 1. $CH_3COO^- + H_2O \longrightarrow CH_4 + HCO_3$
- 2. $4H_2 + HCO_3 + H^+ \longrightarrow CH_4 + 3H_2O$

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What can Affect the Biology of the Process

- Leachate neutralization
- Liquid addition
- Temperature of of the landfill
- Initial aeration

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Summary of the Biological Process

- Decomposition of the deposited waste occurs in a series of phases
- Gas production and leachate quality are linked
- Landfills are complex biological ecosystems

1B - 65

Additional Reading

1. Barlaz, M. A. and R. K. Ham, 1993,"Leachate and Gas Generation," in Geotechnical Practice for Waste Disposal, D. E. Daniel, ed., Chapman and Hall, London, p. 113 - 36.
2. Barlaz, M. A., 1996, “The Microbiology of Municipal Solid Waste Landfills,” in Solid Waste Microbiology, A. C. Palmisano and Barlaz, Morton A.

1B - 66

Leachate Management

- **Refuse contains decomposable matter, as well as the nutrients and organisms that promote decomposition. The limiting factor controlling the amount of decomposition taking place in municipal solid waste is usually the availability of moisture.**
- **The decomposition of solid wastes in an MSW landfill is a complex process. It may be characterized according to the physical, chemical , and biological processes that interact simultaneously to bring about the overall decomposition. Phases previously described.**
- **The by-products of all these mechanisms are chemically laden leachate and landfill gas.**

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Leachate Management

- Leachate is a liquid that has passed through or emerged from the waste in a landfill.
- It contains soluble, suspended, or miscible materials removed from such waste.
  It is imperative, therefore, when designing leachate collection and treatment facilities to consider the concentrations and variability of leachate with regard to its many constituents.
- Leachate generation rates depend on the amount of liquid originally contained in the waste (primary leachate) and the quantity of precipitation that enters the landfill through the cover or falls directly on the waste (secondary leachate).

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Changes in Leachate Compositiion in Different Stages of a Landfill

Parameters with differences between acetic and methanogenic phase

Acetic phase	Average	Range
pH	6.1	4.5-7.5
BOD_5 (mg/l)	13000	4000-40000
COD (mg/l)	22000	6000-60000
BOD_5/COD	0.58	—-
$SO_{4\,(mg/l)}$	500	70-1750
Ca (mg/l)	1200	10-2500
Mg (mg/l)	470	50-1150
Fe (mg/l)	780	20-2100
Mn (mg/l)	25	0.3-65
Zn (mg/l)	5	0.1-120
Methanogenic phase		
pH	8	7.5-9
BOD_5 (mg/l)	180	20-550
COD (mg/l)	3000	500-4500
BOD_5/COD	0.06	—-
SO_4 (mg/l)	80	10-420
Ca (mg/l)	60	20-600
Mg (mg/l)	180	40-350
Fe (mg/l)	15	3-280
Mn (mg/l)	0.7	0.03-45
Zn (mg/l)	0.6	0.03-4

Parameters for which no differences between phases could be observed

	Average	Range
Cl (mg/l)	2100	100-5000
Na (mg/l)	1350	50-4000
K (mg/l)	1100	10-2500
Alkalinity (mg $CaCO_3$/l)	6700	300-11500
NH_4 (mg N/l)	750	30-3000
OrgN (mg N/l)	600	10-4250
Total N (mg N/l)	1250	50-5000
NO_3 (mg N/l)	3	0.1-50
NO_2 (mg N/l)	0.5	0-25
Total P (mg P/l)	6	0.1-30
AOX (ug Cl/l)*	2000	320-3500
As (ug/l)	160	5-1600
Cd (ug/l)	6	0.5-140
Co (ug/l)	55	4-950
Ni (ug/l)	200	20-2050
Pb (ug/l)	90	8-1020
Cr (ug/l)	300	30-1600
Cu (ug/l)	80	4-1400
Hg (ug/l)	10	0.2-50

*adsorbable organic halogen

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Factors Affecting Leachate Generation

- **Climate: Climate at the site significantly influences the leachate generation rate. All other factors being equal, a site located in an area of high precipitation can be expected to generate more leachate.**
- **Topography: Topography affects the site's runoff pattern and the amount of water entering and leaving the site. Landfills should be designed to limit leachate generation from areas peripheral to the site by diverting surface-water "run-on" away from the site and by constructing the landfill cover area to promote runoff and reduce infiltration. All areas of a landfill should maintain at least a two percent grade over the waste at all times to prevent ponding of surface water.**

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Factors Affecting Leachate Generation

- **Landfill cover: Landfill cover at the site affects the amount of water percolating into the landfill to form leachate. As the permeability of the soil used for final cover increases, leachate production rates increase.**
- **Consequently, to reduce the amount of leachate, modern design requires the use of low-permeability clays or geosynthetic membranes in final cover configurations.**
- **Vegetation: Vegetation plays an integral part in leachate control. It limits infiltration by intercepting precipitation directly (thereby improving evaporation from the surface) and by taking up soil moisture and transpiring it back to the atmosphere. A site with a poor vegetative cover may experience erosion that cuts gullies through the cover soil and allows precipitation to flow directly into the land filled waste.**

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Factors Affecting Leachate Generation

- Type of waste: The type of waste and the form that it is in (bulk, shredded, etc.) affect both the composition and quantity of leachate. Wetter wastes, for example,will generate more leachate.

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Predicting Leachate Production Rates

Good landfill design requires predicting the amount of leachate that will be produced. The amount of leachate generated will affect operating costs if leachate collection and treatment are provided. The amount of leachate formed also affects the potential for liner leakage (to be calculated later) and hence to the potential for groundwater contamination. It also affects the cost of post-closure care after the landfill is closed.

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Predicting Leachate Production Rates

Predicting leachate formation requires water-balance calculations.

- Estimating the amount of water from rain or melting snow that will percolate through the landfill cover. Over time, the volume of percolating water will nearly equal the volume of leachate produced.
- There may be a lag between the time percolating water enters the fill material and the time leachate emanates continuously from the base of the fill.
- During this lag period, the solid wastes increase in moisture content until their field capacity is reached (field capacity is defined as the moisture content of the waste above which moisture will flow under the influence of gravity).

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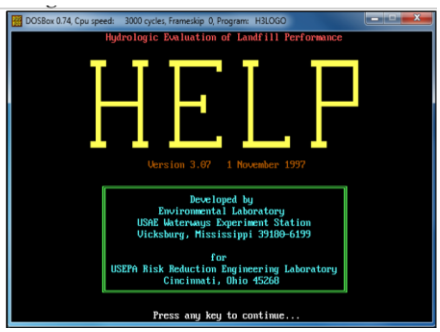
Predicting Leachate Production Rates

The USEPA, in cooperation with the Army Corps of Engineers Waterways Experiment Laboratory, has prepared a computer program that calculates the water balance. The *Hydrologic Evaluation of Landfill Performance* (HELP) Model version 3.0 has weather records in data files and offers options for predicting leachate generation under many combinations of cover conditions.

1B - 75



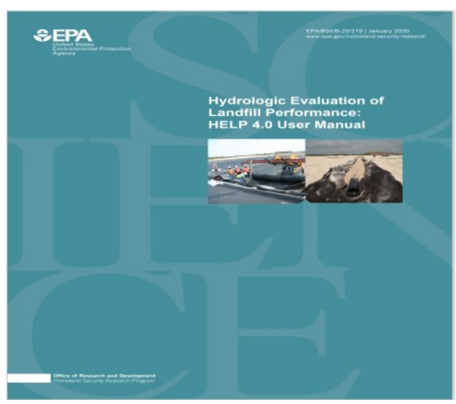
1B - 76

Hydrologic Evaluation of Landfill Performance (HELP)

- HELP program is a quasi two-dimensional hydrologic model that simulates water movement through the landfill.
- The model may be used to estimate water balances under different design scenarios

https://www.epa.gov/land-research/hydrologic-evaluation-landfill-performance-help-model

1B -77



1B - 78

Hydrologic Evaluation of Landfill Performance (HELP)

- The HELP model estimates the following for landfills and bioreactors:
- Quantity of leachate permeating through the waste fill
- Quantity of leachate removed by the leachate collection system
- Quantity of leachate potentially leaking through the bottom liner system
- Depth of hydrostatic head on the primary liner

1B - 79

HELP

The amount of precipitation and leachate that travels through the waste mass can be approximated by the use of Darcy's Law, where

$$Q = kiA$$

Q = flow rate (L^3/T) into landfill

K = permeability of media (L/T)

i = hydraulic gradient (unitless)

A = cross-sectional area (L^2)

1B - 80

HELP

- The permeability of soil and fill materials is a measure of continuous voids. However, a reasonable approximation of the coefficient of permeability must be made, since heterogeneous materials, including cover materials, will yield different permeabilities.
- Differences in waste densities will also yield different permeabilities by as much as 2 orders of magnitude.
- The HELP Model employs a default waste permeability of 1×10^{-3} cm/sec, which is comparable to other hydraulic conductivities cited in literature.

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HELP

- The HELP Model uses three types of input data to estimate hydrologic conditions in landfills:
- climatological data (evapotranspiration, precipitation data, temperature, and solar radiation data), soil data (soil/material interfaces and properties for hydraulic conductivity, wilting point, field capacity, and porosity), and design data (landfill liner system cross-sections including vertical percolation layer, lateral drainage layer, soil layer and geomembrane liner).

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HELP

- The HELP program estimates the amount of moisture that enters the bioreactor as precipitation (rain, snowmelt, etc.), which is then modeled as infiltration through the waste material.
- Water losses through evaporation and biological activity can be accounted for in the program.
- The total amounts of liquid added as recirculation and that fraction collected in the leachate collection system are then estimated by the model.
- To complete the water balance, additional quantities of moisture can be calculated that would be required to maintain the waste fill at the desired field capacity.

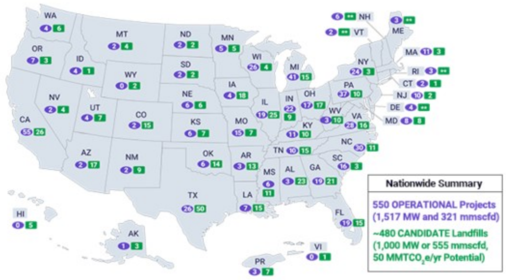
1B - 83

HELP Websites

- Hydrologic Evaluation of Landfill Performance (HELP) Model | US EPA
- 2007_VisualHELP_pg10.cdr (waterloohydrogeologic.com)

1B - 84

Number of Landfill Projects and Data in the United States

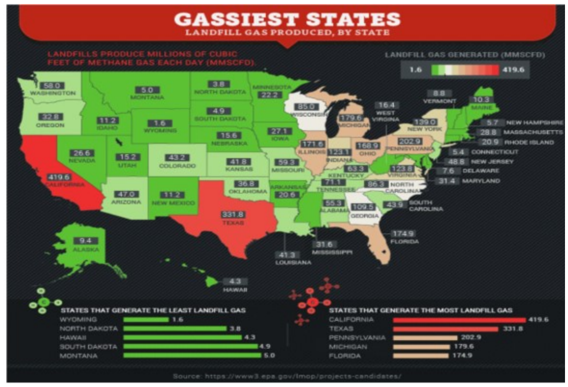


**LMOP does not have information on candidate landfills in this state.

Counts on national map are current as of March 2021.

Project and Landfill Data by State | US EPA

1B - 85



1B - 86

MSW Landfill NESHAP

- On January 16, 2003 USEPA promulgated standards for national emission hazardous air pollutants (NESHAP) for municipal solid waste (MSW) landfills.
- It can be found in the 40 CFR Part 63 Subpart AAAA and was promulgated on January 16, 2003 FR Vol. 68 p.2227

2 - 2

40 CFR Part 63 Subpart AAAA

The intent of the standards is to protect the public health by requiring new and existing sources to control emissions of HAP's to the level reflecting the maximum achievable control technology (MACT)

2 - 3

Subpart AAAA

The final rule ensures reductions of nearly 30 HAP's emitted by MSW landfills including, but are not limited to, vinyl chloride, ethyl benzene, toluene, and benzene.

Each of the HAP's emitted from MSW landfills can cause adverse health effects provided sufficient exposure.

2 - 4

Subpart AAAA

The final rule applies to all MSW landfills that are major sources or are collocated with a major source, and to some landfills that are area sources.

2 - 5

What is the Air Toxics Strategy?

Congress instructed EPA to develop a strategy for air toxics in urban areas that includes specific actions to address the large number of smaller, area sources, and that contains broader risk reduction goals encompassing all stationary sources.

The Air Toxics Strategy is EPA's *integrated* framework for addressing air toxics in those urban areas by looking at stationary, mobile, and indoor source emissions.

Air toxics can pose special threats in urban areas because of the large number of people and the variety of sources of toxic air pollutants, such as cars, trucks, large factories, gasoline stations, landfills and dry cleaners.

The Clean Air Act required EPA to identify a list of at least 30 air toxics that pose the greatest potential health threat in urban areas. As a result, EPA identified a list of 33 air toxics (see attached list) of the 188 toxic air pollutants.

2 - 6

List of the 33 Urban Air Toxics HAPs

acetaldehyde	ethylene oxide
acrolein	formaldehyde
acrylonitrile	hexachlorobenzene
arsenic compounds	hydrazine
benzene	lead compounds
beryllium compounds	manganese compounds
1, 3-butadiene	mercury compounds
cadmium compounds	methylene chloride
carbon tetrachloride +	nickel compounds
chloroform	polychlorinated biphenyls (PCBs)
chromium compounds	polycyclic organic matter (POM)
coke oven emissions +	quinoline
dioxin	1, 1, 2, 2-tetrachloroethane
ethylene dibromide +	perchloroethylene
propylene dichloride	trichloroethylene
1, 3-dichloropropene	vinyl chloride
ethylene dichloride	--

NOTE: A list of 33 urban HAPs which pose the greatest threats to public health in urban areas was listed in the 1999 Strategy. This list of HAPs considered the emissions from major, area and mobile sources. A subset of this list, 30 HAPs, represents the HAPs having the greatest emissions contribution from area sources. A cross (+) denotes the HAPs with less significant emissions contributions from area sources

2 - 7

Air Toxics Strategy website

Integrated Urban Air Toxics Strategy | Urban Air Toxics | US EPA

2 - 8

Subpart AAAA (March 26, 2020)(RTR Analysis)

The final rule is applicable to both major and area sources and contains the same requirements as the Emission Guidelines and New Source Performance Standards(EG/NSPS). (State or Federal)

63.1955 (a) Comply with the requirements of 40 CFR part 60 subpart WWW, subpart XXX, a federal plan or an EPA approved and effective state or tribal plan.

All affected sources must comply with the SSM requirements subpart A of this part as specified in Table 1 and all affected sources must submit compliance reports every 6 months as specified in § 63.1981(h).

2 - 9

Residual Risk and Technology Review (RTTR)

- On March 26, 2020 the RTTR that was conducted and finalized and for the Municipal Solid Waste (MSW) Landfills source category regulated under national emission standards for hazardous air pollutants (NESHAP).
- The EPA also finalized minor changes to the MSW Landfills NSPS and Emission Guidelines (EG) and Compliance Times for MSW Landfills.

2 - 10

Residual Risk and Technology Review

- The results of the chronic baseline inhalation cancer risk assessment indicate that, based on estimates of current actual, allowable, and whole facility emissions under the NESHAP, the maximum individual risk posed by the source category is 10-in-1 million. The total estimated cancer incidence based on actual emission levels is 0.04

TABLE 2—MSW LANDFILLS INHALATION RISK ASSESSMENT RESULTS

Number of facilities [1]	Maximum individual lifetime cancer risk (in 1 million) [2]		Based on actual emissions				
	Based on actual emissions [3] . . .	Based on allowable emissions . . .	Estimated population at increased risk of cance ≥1-in-1 million	Estimated population at increased risk of cancer ≥10-in-1 million	Estimated annual cancer incidence (cases per year)	Maximum chronic noncancer TOSHI [4]	Maximum screening acute noncancer hazard quotient (HQ)
706	10 (p-dichlorobenzene, ethyl benzene, benzene).	10 (p-dichlorobenzene, ethyl benzene, benzene).	18,300	11	0.04	0.1 (neuro-logical)	HQ_{REL}[5] = 0.07 (chloroform).

[1] Number of facilities evaluated in the risk analysis.
[2] Maximum individual excess lifetime cancer risk due to HAP emissions from the source category.
[3] Whole facility emissions are equal to actual emissions and have the same risk.
[4] Maximum TOSHI. The target organ systems with the highest TOSHI for the source category are neurological, with risk driven by emissions of trichloroethylene, m-xylene, xylenes (mixed), and tetrachloroethene from fugitive emissions.
[5] Reference Exposure Level (REL).

Residual Risk and Technology Review

- Our risk analysis indicated the risks from this source category are low for both cancer and noncancer health effects, and, therefore, any additional emissions reductions would result in minimal health benefits or reductions in risk.
- Based upon results of the risk analysis and our evaluation of the technical feasibility and cost of the option(s) to reduce landfill fugitive emissions, we proposed that the current NESHAP provides an ample margin of safety to protect the public health.
- We also proposed, based on the results of our environmental screening assessment, that more stringent standards are not necessary to prevent an adverse environmental effect.

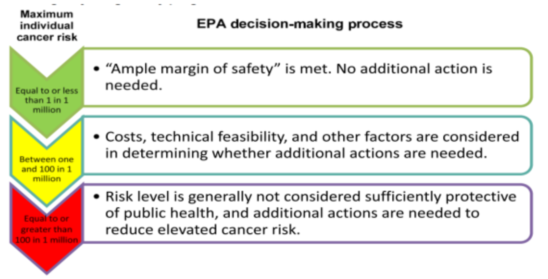
2 - 12

Residual Risks

- For cancer risks > 10^{-4}, EPA will set a residual risk standard (health based).
- For cancer risks < 10^{-6} EPA will not set a residual risk standard.
- For cancer risks in between 10^{-6} & 10^{-4}, EPA will consider costs, technical feasibility, location of people near facility, etc. in deciding on whether to set a residual risk standard.
- For non-cancer risks, EPA will look at target organ hazard info. in deciding on whether to issue a residual risk std.

13

EPA decision-making process for addressing residual risk for carcinogens in the Agency's regulatory program



Source: OIG summary of information from the EPA. (EPA OIG image)

Note: A maximum individual risk level of less than 100 in one million is generally considered acceptable, but the overall determination of risk acceptability and ample margin of safety are also dependent on other health measures and factors, including the chronic and acute non-cancer risks, number of people exposed at various risk levels, and uncertainties.

14

NESHAP AAAA Control Requirements

- **Contains same requirements as NSPS/EG**
- **Requires gas collection and control system (GCCS) for same landfills as NSPS/EG:**
- **Design capacity ≥ 2.5 million Mg or 2.5 million m^3 and estimated uncontrolled NMOC emissions ≥ 50 (34 for XXX) Mg/yr**
- **Requires more timely control of bioreactors**

2 - 15

Part 63 Subpart AAAA
National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills (11/8/87)

- **63.1935 Applicability**
- A MSW landfill is subject to the National Emission Standards for Hazardous Air Pollutants (NESHAPS) MSW Maximum Achievable Control Technology (MACT) if meeting the following criteria:
  - The landfill has accepted waste since 11/8/87 and meets any one of the following criteria:
    - The MSW landfill is a major source* as defined in 40 CFR 63.2 of Subpart A or if it is collocated with a major source
    - The MSW landfill is an area source that has a design capacity ≥ 2.5 million MG and 2.5 million m3 and has estimated uncontrolled emissions ≥ 50 MG/yr NMOC .
    - The MSW landfill uses a **bioreactor** and has a design capacity ≥ 2.5 million MG and 2.5 million m^3 and is no permanently closed as of 1/16/03.

2 - 16

Part 63 Subpart AAAA
National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills

- **63 Subpart AAAA Requirements:**
- Landfill must comply with 40 CFR 60 Subpart WWW or 40 CFR 60 Subpart Cc, whichever is applicable **§ 63.1955**.
- Landfill must keep records and reports as specified in 40 CFR 60 Subpart WWW or Subpart Cc, whichever is applicable. Landfill must submit the **annual report described in 40 CFR 60.757(f) every 6 months** (§ 63.1980(a))
- Recordkeeping and reporting requirements for bioreactors §63.1980(b) to (h).
- **Major source* means any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has the potential to emit considering controls, in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants, unless the Administrator establishes a lesser quantity, or in the case of radionuclides, different criteria from those specified in this sentence.

2 - 17

Purpose of the Original NSPS/EG Regulation

- **Limit LFG migration subsurface off site**
- **Limit LFG migration into onsite structures**
- **Limit LFG odors at or beyond the landfill boundary**
- **Limit LFG emissions into the atmosphere**

2 - 18

EG/NSPS

Subpart Cc (Cf) – Emission Guidelines (EG) and Compliance Times for Municipal Solid Waste Landfills (March 12, 1996)(August 29, 2016)

§ 60.33c (60.33f)

a) For approval, a State plan shall include control of MSW landfill emissions at each MSW landfill meeting the following three conditions:

2 - 19

EG/NSPS

(1) The landfill has accepted waste at any time since November 8, 1987, or has additional design capacity available for future waste deposition;

(2) The landfill has a design capacity greater than or equal to 2.5 million megagrams and 2.5 million cubic meters. The landfill may calculate design capacity in either megagrams or cubic meters for comparison with the exemption values. Any density conversions shall be documented and submitted with the design capacity report; and

(3) The landfill has a non-methane organic compound emission rate of 50 (34) megagrams per year or more.

2 - 20

EG/NSPS

(b) For approval, a State plan shall include the installation of a collection and control system meeting the conditions provided in

§ 60.752(b)(2)(ii) of this part at each MSW landfill meeting the conditions in paragraph (a) of this section. The State plan shall include a process for State review and approval of the site-specific design plans for the gas collection and control system(s).

2 - 21

EG/NSPS

(c) For approval, a State plan shall include provisions for the control of collected MSW landfill emissions through the use of control devices meeting the requirements of paragraph

(c)(1), (2), or (3) of this section, except as provided in § 60.24.

2 - 22

EG/NSPS

§ 60.752 Standards for air emissions from municipal solid waste landfills.

(a) Each owner or operator of an MSW landfill having a design capacity less than 2.5 million megagrams by mass or 2.5 million cubic meters by volume shall submit an initial design capacity report to the Administrator as provided in § 60.757(a). The landfill may calculate design capacity in either megagrams or cubic meters for comparison with the exemption values.

2 - 23

Subpart GGG

- Federal Plan Requirements for Municipal Solid Waste Landfills That Commenced Construction Prior to May 30, 1991 and Have Not Been Modified or Reconstructed Since May 30, 1991.
- A municipal solid waste landfill regulated by an EPA approved and currently effective State or Tribal plan is not subject to the requirements of this subpart. States that have an approved and effective State plan are listed in table 1 of this subpart. Not withstanding the exclusions in table 1 of this subpart, any MSW landfill located in a State or portion of Indian country that does not have an EPA approved and currently effective State or Tribal plan is subject to the requirements of this subpart.

2 - 24

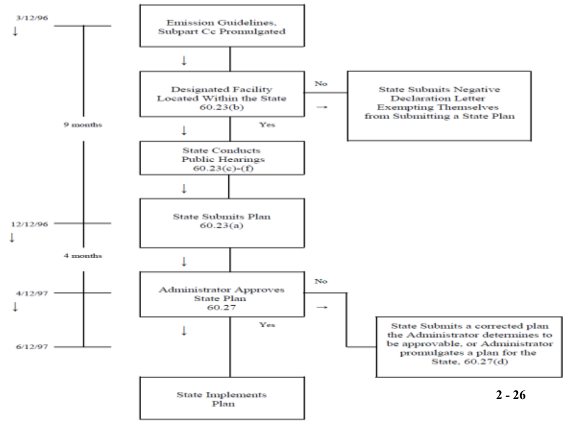
EG/NSPS

Subpart WWW—Standards of Performance for Municipal Solid Waste Landfill (March 12, 1996)

§ 60.750 Applicability, designation of affected facility, and delegation of authority.

(a) The provisions of this subpart apply to each municipal solid waste landfill that commenced construction, reconstruction or modification on or after May 30, 1991. Physical or operational changes made to an existing MSW landfill solely to comply with Subpart Cc of this part are not considered construction, reconstruction, or modification for the purposes of this section.

2 - 25



2 - 26

40 CFR Part 63, Subpart AAAA

The rule applies to area source landfills if they have a design capacity equal to or greater than 2.5 million Mg and 2.5 million m³, and they have estimated uncontrolled emissions of 50 Mg/yr NMOC or more, or are operated as a bioreactor.

2 - 27

Subpart AAAA

The rule applies to area source landfills if they have a design capacity equal to or greater than 2.5 million Mg and 2.5 million m³, and they have estimated uncontrolled emissions of 50 Mg/yr NMOC or more, or are operated as a bioreactor.

2 - 28

40 CFR Part 63, Subpart AAAA

- **The final rule adds startup, shutdown, and malfunction (SSM) requirements, adds operating condition deviations for out of-bounds monitoring parameters, requires timely control of bioreactor landfills, and changes the reporting frequency for compliance monitoring report to every 6 months.**

2 - 29

The final rule requires operation of the control device(s) within the operating parameter boundaries as described in 40 CFR 60.758(c)(1) and to continuously monitor control device operating parameters

2 - 30

Compliance with the operating conditions is demonstrated when monitoring data show that the gas control devices are operated within the established operating parameter range. Compliance also occurs when the data quality is sufficient to constitute a valid hour of data in a 3-hour block period.

2 - 31

United States Environmental Protection Agency

Office of Air Quality Planning and Standards Research Triangle Park, NC 27711

EPA-453R/96-004 February 1999

Air

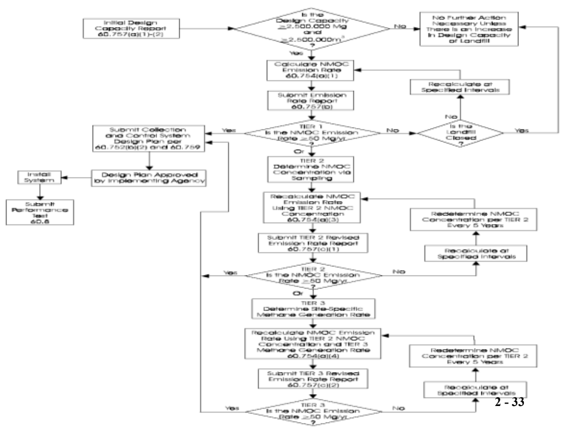
EPA

Municipal Solid Waste Landfills, Volume 1:

Summary of the Requirements for the New Source Performance Standards and Emission Guidelines for Municipal Solid Waste Landfills

FINAL

2 - 32



2 - 33

More Information

www.epa.wer/non-

Municipal Solid Waste Landfills | Landfills | US EPA

reduce.htm

2 - 34

NSPS/EG Requirements

- GCCS must be designed for the maximum expected flow over the intended use period
- The flow used for the design must be equal to or greater than flows estimated by EPA Model w/ AP-42 defaults for Lo and k. Site specific k from Method 2E may be substituted. [§ 60.755(a)(1)]

2 - 35

60.752 Standards for air emissions from municipal solid waste landfills.
(b) Each owner or operator of an MSW landfill having a design capacity equal to or greater than 2.5 million megagrams and 2.5 million cubic meters, shall either comply with paragraph (b)(2) of this section or calculate an NMOC emission rate for the landfill using the procedures specified in § 60.754. The NMOC emission rate shall be recalculated annually, except as provided in § 60.757(b)(1)(ii) of this subpart. The owner or operator of an MSW landfill subject to this subpart with a design capacity greater than or equal to 2.5 million megagrams and 2.5 million cubic meters is subject to part 70 or 71 permitting requirements.

2 - 36

(2) If the calculated NMOC emission rate is equal to or greater than 50 megagrams per year, the owner or operator shall:
(i) Submit a collection and control system design plan prepared by a professional engineer to the Administrator within 1 year:
(A) The collection and control system as described in the plan shall meet the design requirements of paragraph (b)(2)(ii) of this section.
(B) The collection and control system design plan shall include any alternatives to the operational standards, test methods, procedures, compliance measures, monitoring, recordkeeping or reporting provisions of §§ 60.753 through 60.758 proposed by the owner or operator.

2 - 37

(D) The Administrator shall review the information submitted under paragraphs (b)(2)(i) (A),(B) and (C) of this section and either approve it, disapprove it, or request that additional information be submitted. Because of the many site-specific factors involved with landfill gas system design, alternative systems may be necessary. A wide variety of system designs are possible, such as vertical wells, combination horizontal and vertical collection systems, or horizontal trenches only, leachate collection components, and passive systems.

2 - 38

§ 60.754 Test methods and procedures.
(a)(1) The landfill owner or operator shall calculate the NMOC emission rate using either the equation provided in paragraph (a)(1)(i) of this section or the equation provided in paragraph (a)(1)(ii) of this section. Both equations may be used if the actual year-to-year solid waste acceptance rate is known, as specified in paragraph (a)(1)(i), for part of the life of the landfill and the actual year-to-year solid waste acceptance rate is unknown, as specified in paragraph (a)(1)(ii), for part of the life of the landfill.

2 - 39

(continued)

- **The values to be used in both equations are 0.05 per year for k, 170 cubic meters per megagram for Lo, and 4,000 parts per million by volume as hexane for the CNMOC. For landfills located in geographical areas with a thirty year annual average precipitation of less than 25 inches, as measured at the nearest representative official meteorological site, the k value to be used is 0.02 per year.**

2 - 40

$$M_{NMOC} = \sum_{i=1}^{n} 2\ k\ L_o M_i \left(e^{-kt}i\right)\left(C_{NMOC}\right)\left(3.6\times 10^{-9}\right)$$

where,
MNMOC=Total NMOC emission rate from the landfill, megagrams per year
k=methane generation rate constant, year $^{-1}$
Lo=methane generation potential, cubic meters per megagram solid waste
Mi = mass of solid waste in the ith section, megagrams
ti=age of the ith section, years
CNMOC=concentration of NMOC, parts per million by volume as hexane
t = age of landfill, years
CNMOC=concentration of NMOC, parts per million by volume as hexane
c=time since closure, years; for active landfill c=O and e = kc1
3.6×10^{-9} =conversion factor

2 - 41

Gas collection systems are not 100 percent efficient in collecting landfill gas, so emissions of CH4 and NMOCs at a landfill with a gas recovery system still occur.
To estimate controlled emissions of CH4, NMOCs, and other constituents in landfill gas, the collection efficiency of the system must first be estimated.
Reported collection efficiencies typically range from 60 to 85 percent, with an assumed average of 75 percent. If site-specific collection efficiencies are available, they should be used instead of the 75 percent average.

2 - 42

$$\text{Controlled Landfill Emissions} = P\left(1 - \frac{\text{Percent Collection Efficiency}}{100}\right) + P\left(\frac{\text{Percent Collection Efficiency}}{100}\right) * \left(1 - \frac{\text{Percent Control Efficiency}}{100}\right)$$

<u>Example of Landfill NMOC Collection and Control</u>

VOC emissions from Landfill A are estimated to be 3,197 cubic meters per year.
Average collection efficiency of the landfill gas recovery system is not known at Landfill A, so a 75-percent collection efficiency rate is assumed. The collected landfill gas is controlled by a flare, which has a control efficiency for NMOCs of 83.16 percent.
Controlled NMOC Emissions = 3,197 m^3 * [1 - 0.75] + 3,197 m^3 * [0.75] * [1 - 0.8316]

= 799.25 m^3 + 3,197 m^3 * 0.1263
= 799.25 m^3 + 403.78 m^3
= 1,203 m^3

Regulatory History

1996	Issued New Source Performance Standard (NSPS) and Emission Guidelines (EG) Final Rule • NSPS for new or modified landfills (40 CFR Part 60, Subpart WWW) • EG for existing landfills (40 CFR Part 62, Subpart Cc)
1999	Issued Federal Plan: Requirements for existing landfills (40 CFR Part 62, Subpart GGG)
2003	Issued National Emission Standard for Hazardous Air Pollutants (NESHAP) Final Rule (40 CFR Part 63, Subpart AAAA)
2016	Issued New Source Performance Standard (NSPS) and Emission Guidelines (EG) Final Rule • NSPS for new or modified landfills (40 CFR Part 60, Subpart XXX) • EG for existing landfills (40 CFR Part 62, Subpart Cf): *Deadline Litigation*
2020	Completed NESHAP risk and technology review (RTR) Final Rule
2021	Issued Final Federal Plan: Requirements for existing landfills • Implements EG and Compliance Times (40 CFR Part 62, Subpart OOO) • Applies to landfills in states and Indian country where state/tribal plans are not in effect

EPA focuses on a new set of regulations: covers existing landfills and new/modified landfills

MSW Landfill Regulations: Summary Table

	New/Modified Landfills	Existing Landfills		
	Part 60 NSPS (new or modified)	Part 60 Emission Guidelines (EG) under State Plan for existing landfills that have not triggered NSPS	Part 62 Federal Plan for states without approved state plans implementing EG	Part 63 NESHAP
1st Generation	WWW (1996)	Cc (1996)	GGG (1999)	AAAA (2003)
2nd Generation	XXX (2016) (commenced construction, reconstruction, or modification **after** July 17, 2014)	Cf (2016) (commenced construction, reconstruct	OOO (2021) (commenced construction, reconstruction, or modification on or before July 17, 2014)	AAAA (2020)

Part 60 Subpart Cc- Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills (11/8/87 to 5/29/91) FR 3/12/96

- **Designated facilities-** each existing MSW landfill for which construction, reconstruction, or modification was commenced before 5/30/91
- **For approval, a State plan shall** include control of MSW landfill emissions at each MSW landfill meeting the following 3 conditions:
  - existing landfills that have accepted waste since 11/8/87 or has additional design capacity to accept waste
  - landfill with design capacity ≥2.5 million megagrams by mass or ≥ 2.5 million cubic meters by volume
  - landfill has a NMOC emission rate of ≥50 megagrams/yr

Part 60 Subpart Cf- Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills (FR 8/29/2016)

- **60.31f Designated facilities.**

(a) The designated facility to which these Emission Guidelines apply is each existing MSW landfill for which construction, reconstruction, or modification was commenced on or before July 17, 2014.

Part 60 Subpart Cc (Cf)-Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills (11/8/87 to 5/29/91)

- **For approval, a State plan shall include** the requirement for existing landfills to install a collection and control system meeting the requirements:
  - An open flare designed and operated in accordance with the parameters established in §60.18.
  - A control system designed and operated to reduce NMOC by 98% by weight.
  - An enclosed combustor designed and operated to reduce the outlet NMOC concentration to 20 ppm as hexane by volume, on a dry basis at 3% O2 or less.

2 - 49

Applicability of Part 60 Subpart Cc; Part 60 Subpart WWW;

- Part 60 Subpart Cc-Emission Guidelines is for existing MSW landfill for which construction, reconstruction, or modification was commenced before 5/30/91, but incorporates all of the requirements of Subpart WWW.
- NSPS Subpart WWW is applicability to all landfills constructed, reconstructed, or modified on or after 5/30/91

2 - 50

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- Landfills with a design capacity **< 2.5 million megagrams by mass** or **< 2.5 million cubic meters by volume** shall submit an initial design capacity report to the Director.
- If the design capacity **equals or exceeds 2.5 million megagrams** or **2.5 million cubic meters** the owner shall calculate an annual NMOC emission rate for the landfill.
- If the calculate NMOC is calculated to **< 50 (34) megagrams/yr** the owner will recalculate the NMOC annually and submit an annual emission report.

2 - 51

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills 60.757(b)(1)(ii)

- NMOC emission rate reports are submitted to the State Agency annually, with the following exception:
- If the estimated NMOC emission rate is **less than 50 (34) MG/yr in each of the next 5 consecutive years**, based on the estimated waste acceptance rate, the owner may elect to submit the report **every 5 years**, and if all the data and calculations upon which the estimate is based is provided in the report.
- If the actual waste acceptance rate is exceeded in any year reported in the 5-year estimate, a revised 5-year report shall be submitted beginning with year in which the actual acceptance rate exceeded the estimated rate.

2 - 52

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

The owner has the option to recalculate the NMOC emissions in 3 Tiers to document the annual emissions to be < 50 (34) MG :

- Tier 1: NMOC emissions calculations (2) use default values set in 60.754(a)(1)
- Tier 2: Determine the site-specific NMOC emission rate (at least every 5 yrs.)
  - install at least 2 sample probes per hectare of landfill surface that has been in waste for 2 years, up to a maximum of 50 probes;
  - analyze one sample of landfill gas from each probe to determine the NMOC concentration using Method 25 or 25C;
  - composite samples from different probes to one cylinder are allowed if equal sample volumes are taken from each probe; and
  - the average site-specific NMOC concentration is used instead of the default value in Tier 1, in one of the 2 calculations contained in 60.754(a)(1)
- Tier 3: The site-specific CH4 generation rate constant is determined using Method 2E (rather than the default value), along with the site-specific NMOC concentration measured in Tier 2. CH4 generation rate constant perf. only once.

2 - 53

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- The owner shall submit a collection and control system design plan (prepared by a professional engineer) within 1 year of the first report in which the NMOC emission rate exceeds 50 (34) MG/yr; except where NMOC emissions are re-calculated to be less than this amount using Tier 2 or Tier 3.
- The owner shall install a collection and control system within 30 months after the 1st annual report in which NMOC emissions exceed 50 MG/yr.
- Each well shall be installed no later than 60 days after the date on which the initial solid waste has been in place for a period of (§60.755(b)):
  - 5 years or more if active; or 2 years or more if closed or at final grade
  - Collected gases shall be routed to a control device meeting one of the following requirements:
    - An open flare designed and operated in accordance with the parameters established in §60.18.
    - A control system designed and operated to reduce NMOC by 98% by weight.
    - An enclosed combustor designed and operated to reduce the outlet NMOC concentration to 20 ppm as hexane by volume, on a dry basis at 3% O2 or less.

2 - 54

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills (60.753) (60.763)

Operational standards for collection and control systems

- The gas collection system must be operated under negative pressure at each wellhead, except under the following conditions:
  - a fire or increased well temperature (maintain records and report)
  - use of a geomembrane or synthetic cover
  - a decommissioned well, w/ declined flows (capped not removed)
- Operate each interior wellhead with a landfill gas temperature less than 55° C (131 F°) and with either oxygen less than 5% or nitrogen less than 20% **(For XXX O2 does not have limits nor need to be reported, but should be recorded,**
- A **higher operating value demonstration** shall show supporting data that the elevated parameter does not cause fires or significantly inhibit anaerobic decomposition by killing methanogens.
- Operate the collection system so methane concentration is < 500 ppm above background at the surface of the landfill.

2 - 55

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- The following procedures shall be used for compliance w/ the **surface methane** operational standards:
  - The owner shall monitor the surface CH4 concentrations along the entire perimeter of the collection area and along a pattern that transverses the landfill at 30 meter intervals on a quarterly basis using an organic vapor analyzer, flame ionization detector, or other portable monitoring device meeting the requirements of § 60.755(d).
  - The background concentration shall be determined by moving the probe upwind and downwind outside the boundary of the landfill at a distance of 30 meters from the perimeter wells.
  - Surface CH4 monitoring shall be performed in accordance w/ Section 4.3.1 of Method 21, except the probe inlet shall be placed 5 to 10 cm from the ground; and monitoring shall be conducted during normal meteorological conditions.

2 - 56

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- For the purposes of identifying the **infiltration of excess air**, the wellhead shall be monitored monthly for temperature and nitrogen or oxygen to demonstrate compliance with § 60.753(c).
  - Actions shall be initiated to correct the exceedance within 5 days of the measured exceedance.
  - If any exceedance cannot be achieved within 15 days of the 1st measurement, the gas collection system shall be expanded within 120 days of the initial exceedance.
  - An **alternative timeline** for correcting the exceedance may be submitted to the Director for approval.

2 - 57

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- The **gauge pressure** shall be measured monthly in the gas collection header at each individual well. If positive pressure exists the following procedures shall be followed:
  - Actions shall be initiated to correct the exceedance within 5 days, except for the 3 conditions allowed in § 60.753(b) (fire, geomembrane, decommissioned well).
  - If negative pressure cannot be achieved without excess air infiltration within 15 days of the 1st measurement, the gas collection system shall be expanded within 120 days of the initial measurement of + pressure.
  - An **alternative timeline** for correcting the exceedance may be submitted to the Director for approval.

2 - 58

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- Any reading of 500 ppm CH4 or more above background shall be recorded as an exceedance. The exceedance is not a violation if the following procedures are followed:
  - The location of each monitored exceedance shall be marked and the location recorded.
  - Cover maintenance or adjustments to the vacuum of the adjacent wells is made to increase the gas collection in the vicinity of the exceedance.
  - The location is re-monitored w/i 10 days of detecting the exceedance and it is corrected;
  - Or if, w/i 10 days, the location is monitored with a 2nd exceedance, additional corrective action is taken; and the location is re-monitored w/i 10 days of the 2nd exceedance.
  - Any location showing an exceedance , where the CH4 conc. is re-monitored to be< 500 ppm over background, shall be monitored w/i 1 mo. of the initial exceedance.
  - Any location showing an exceedance of 500 ppm above background 3 times in a quarterly period, shall have a new well installed w/i 120 days of the initial exceedance.
  - An **alternative remedy** to the exceedance such as upgrading the blower, header pipes, or control device may be submitted to the Director for approval.

2 - 59

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- The calculation for the maximum expected gas generation flow rate from the landfill to determine the design of the collection and control system is provided in § 60.755(d).
- A value of no more than 15 years shall be used for the intended use period of the gas mover equipment. The active life of the landfill is the age of the landfill plus the estimated number or years until closure.
- The collection and control system shall be designed to control and extract gas from all portions of the landfill sufficient to meet all of the operational and performance standards of the NSPS.
- The owner shall monitor for the cover integrity and implement cover repairs as necessary on a monthly basis.

2 - 60

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

Each owner demonstrating compliance through the use of an **enclosed combustor** shall install, calibrate, operate, and maintain, according to mfg's specifications, the following equipment:

- A temperature monitoring device equipped with a continuous recorder, except a temperature monitoring device is not required for boilers or process heaters > 44 MW.
- A device that records flow to or bypass of the control device using either of the following methods:
  - Install, calibrate, and maintain a gas flow rate measuring device that records the flow to the control device at least every 15 minutes; or
  - Secure the bypass line valve in the closed position with a car-seal or lock-and-key, w/ a visual inspection at least once/month.

2 - 61

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- Each owner demonstrating compliance w/ and **open flare** shall install, calibrate, operate, and maintain, according to mfg's specifications, the following equipment:
  - a heat sensing device, such as an ultraviolet beam sensor or thermocouple, at the pilot light or the flame itself, to indicate the continuous presence of a flame.
  - A device that records the flow to or bypass of the flare, using either of the following methods:
    - Install, calibrate, and maintain a gas flow rate measuring device that records the flow to the flare at least every 15 minutes; or
    - Secure the bypass line valve in the closed position with a car-seal or lock-and-key, w/ a visual inspection at least once/month.

2 - 62

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- Requirements for surface CH4 monitoring devices:
  - The portable analyzer shall meet the instrument specifications in Section 3 of Method 21, except CH4 will replace VOC.
- The provisions of this subpart apply at all times, except during periods of start-up, shutdown, or malfunction provided the duration of start-up, shutdown, or malfunction:
  - does not exceed 5 days for the collection systems and
  - does not exceed 1 hour for the control devices.

2 - 63

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- The owner shall submit an **equipment removal report** 30 days prior to removal or cessation of operations of the control equipment which shall include:
  - A copy of the closure report;
  - A copy of the initial performance test report demonstrating that the collection and control equipment has been in place for a minimum of 15-years; and
  - Dated copies of 3 successive NMOC emission rate reports, calculated no less than 90 days or more than 180 days apart, demonstrating that the landfill is producing < 50 MG NMOC/yr.

2 - 64

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- Any **closed landfill** that has no monitored exceedances of the 500 ppm CH4 over background limitation in 3 consecutive quarterly monitoring periods may skip to annual monitoring, but shall return to quarterly if an exceedance is detected.
- The owner shall submit a **closure report** within **30 days** of waste acceptance cessation. No additional wastes may be accepted following the report without filing a notice of modification.

2 - 65

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- **Annual (Biannual) Report** The owner using an active collection system for compliance shall submit biannual reports to the Director containing the following information:
  - Value and length of time for any exceedance of any parameters monitored under § 60.756(a) thru (d), i.e., pressure, temp., O2/N2 measurements at wellhead; continuous temp. records for enclosed combustor or flow measurement requirements for flare, etc.
  - Description and duration of all periods when the gas stream was diverted from the control device through a bypass line or there was an indication of a bypass.
  - Description and duration of all periods when the control device was not in operation for a period exceeding 1 hour and length of time it was not in operation.
  - All periods when the collection system was not operating in excess of 5 days.
  - The location of each exceedance of the 500 ppm CH4 concentration over background and the concentration recorded at each such location the following month.
  - The date of installation and location of each well or collection system expansion added to comply with § 60.755.

2 - 66

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- The following exceedances shall be reported in the annual (or semiannual) report:
  - For enclosed combustors, except for boilers or process heater with a design heat input capacity ≥ 44 MW (150 MMBtu/hr):
    - All 3-hr. periods of operation during which the avg. combustion temp. was more than 28° C below the avg. combustion temp. maintained during the most recent compliance test.
  - For all boilers and process heaters, any change in the location at which the landfill gas vent stream is introduced into the flame zone from that maintained during the performance or compliance demonstration.

2 - 67

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- The **initial performance test report** for the collection and control system shall include the following information:
  - A diagram of the collection system showing all locations including: all wells, horizontal collectors, surface collectors, or other gas extraction devices;
  - This diagram shall include the locations excluded from the collection area (non-organic/non-productive) and any proposed areas for future collection system expansion;
  - The data upon which the sufficient density of wells, horizontal collectors, surface collectors, or other extraction devices and the gas mover equipment sizing was based;
  - Documentation of the presence of asbestos or nondegradable material for each area from which collection wells have been excluded;
  - The sum of the gas generation flow rates and calculations of these flow rates for all areas for which collection wells have been excluded based on non-productivity;
  - Provisions for increasing gas mover equipment capacity with increased gas generation, if the present gas moving equipment is inadequate to move the maximum flow rate expected over the life of the landfill;
  - The provisions for control of off-site migration of landfill gases.

2 - 68

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

Recordkeeping requirements

- Each landfill owner subject to §60.752(b) shall keep, for at least 5 years, up-to-date readily accessible records, of the design capacity report, the current amount of solid waste in place, and the year-by-year acceptance rate.
- Each landfill owner shall keep up-to-date, readily accessible records, and for the life of the control equipment, the data measured during the initial performance test or compliance determination. Records of subsequent test or monitoring shall be maintained for a minimum of 5 years.
- Records of control device vendor specifications shall be maintained until its removal.

2 - 69

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

Recordkeeping requirements (cont.)

- For a facility required to install a **collection and control system**:
  - The maximum expected gas generation flow rate calculated as required per §60.755(a)(1); and
  - The density of wells, horizontal collectors, surface collectors, or other gas collection devices using procedures specified in §60.759(a)(1).
- Where using an **enclosed combustor,** other than a boiler or process heater with a design heat input capacity ≥ 44 MW:
  - The average combustion temperature measured at lest every 15 minutes and averaged over the same time period as the performance test; and
  - The % reduction of NMOC or outlet NMOC concentration , measured as required per §60.752(b)(2)(iii)(B) for the control device.

2 - 70

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

Recordkeeping requirements (cont.)

- Where using an **open flare** to demonstrate compliance:
  - The flare type (steam-assisted, air-assisted, or nonassisted); and
  - All visible emission readings;
  - The heat content determination;
  - The flow rate or bypass flow rate measurements;
  - The exit velocity determinations made during the performance test as specified in §60.8;
  - Continuous records of the flare pilot flame or flare flame monitoring equipment; and
  - Records of all periods of operations during which the pilot flame to the flare flame is absent.

2 - 71

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

Recordkeeping requirements (cont.)

- Where using a **boiler or process heater of any size** for compliance:
  - A description of the location at which the collected gas vent stream is/was introduced into the boiler/process heater during the performance test; and documentation that it is not moved without a new compliance demonstration.
- Each owner of a controlled landfill, subject to the provisions of this subpart, shall keep for 5 years, up-to-date and readily accessible:
  - Continuous records of equipment operating parameters specified to be monitored as required by §60.756; and
  - Periods of operation during which the parameter boundaries established during the most recent performance test were exceeded.

2 - 72

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- **Recordkeeping requirements (cont.)**

  Where using a **boiler or process heater** with a design heat input capacity ≥ 44 MW for compliance:

  all periods of operation of the boiler/process heater, e.g., to include records of steam use, fuel use, or monitoring date required per a State permit.

  Where using an **open flare** to demonstrate compliance:

  continuous records of the flame or flare pilot flame monitoring required per §60.756(c); and

  all periods of operation during which the flame or flare pilot flame is absent.

2 - 73

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

Recordkeeping requirements (cont.)

- Each owner of a **controlled landfill**, subject to the provisions of this subpart, shall keep for the lifetime of the collection system:
  - An update, readily accessible plot map showing each existing and planned collector system and the identification of each to include:
    - The installation date and location of all newly installed collectors; and
    - Documentation of the nature, date of deposition, amount, and location of asbestos-containing, nondegradable, and non-productive wastes excluded from the collection areas

2 - 74

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

Recordkeeping requirements (cont.)

- Each owner of a controlled landfill, subject to the provisions of this subpart, shall keep up-to-date and readily accessible continuous records of:

  The flow to the control device and the indication of any/every bypass flow to the control device; and

  The monthly inspection of the car-seals or lock-and-key configurations used to seal bypass lines.
- Land owners who convert design capacity from volume to mass or mass to volume, to demonstrate that the landfill capacity is less than 2.5 million MG or 2.5 million cubic meters, shall keep readily accessible records of the annual recalculation of site-specific density, design capacity and the supporting documentation of the conversion from mass to volume or volume to mass.

2 - 75

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- Each owner of a **controlled landfill**, subject to the provisions of this subpart, shall keep for 5 years, up-to-date and readily accessible records for:
  - All collection and control system exceedances of the operational standards required per §60.753;
  - The readings in the subsequent month, whether or not the 2nd reading is an exceedance; and

2 - 76

Part 60 Subpart WWW (XXX) Standards of Performance for Municipal Solid Waste Landfills

- Any **nonproductive area of the landfill may be excluded** from control provided that the total of all excluded areas can be shown to contribute less than 1% of the total amount of NMOC emissions from the landfill. The amount, location, and age of the material shall be documented and provided to the Director upon request. A separate NMOC emissions estimate shall be made for each section proposed for exclusion, and the sum of all such sections shall be compared to the NMOC emissions estimate for the entire landfill. Emissions from each section shall be computed using the formula in this paragraph, where Qi = NMOC emission rate from the section, in MG/yr.
- All gas collection devices shall be constructed of polyvinyl chloride (PVC), high density polyethylene (HDPE) pipe, fiberglass, stainless steel, or other nonporous resistant material of suitable dimensions to withstand environmental and operational stresses of a landfill.

2 - 77

NSPS XXX Rule Applicability

- NSPS XXX applies to MSW LFs that commenced construction, reconstruction, or modification after July 17, which is an increase in the permitted volume design capacity by either lateral or vertical expansion based on its permitted design capacity as of July 17, 2014.

2 - 78

40 CFR 60 Subpart XXX (cont.) § 60.765 Compliance procedures

- Monitoring of operations
- Reporting requirements
- Recordkeeping requirements
- Specifications for active CS

2 - 79

40 CFR 60 Subpart XXX (cont.)

- Calculated NMOC Emission Rate. Submit a collection and control system design plan prepared by a professional engineer to the Administrator within 1 year as specified in §60.767(c); calculate NMOC emissions using the next higher tier in §60.764; or conduct a surface emission monitoring demonstration using the procedures specified in §60.764(a)(6). The collection and control system must meet the requirements in paragraphs (b)(2)(ii) and (iii) of this section.
- The collection devices within the interior must be certified to achieve comprehensive control of surface gas emissions by a professional engineer. The following issues must be addressed in the design: Depths of refuse, refuse gas generation rates and flow characteristics, cover properties, gas system
- Current WWW plan applies and continue to follow WWW until agency approval and also while upgrading GCCS and other monitoring requirements to meet XXX. Any new XXX requirements, must state that these are prospective (ability to isolate, treatment plan, going forward, the GCCS design plan must be revised within 90 days of expanding operations to an area not covered by the previously approved design plan and/or before installing/expanding the GCCS in a manner inconsistent with the previous design plan.

2 - 80

Reference Documents:

- Part 60 **Subpart Cf- Emission Guidelines** and Compliance Times for Municipal Solid Waste Landfills
- Part 60 **Subpart XXX Standards of Performance for Municipal Solid Waste Landfills**
- Part 60 Subpart A, **§60.18**- Standards of Performance for New Stationary Sources, General Provisions, General control device and work practice requirements for a **flare**
- Part 63 Subpart A, **§63.11**- National Emission Standards for Hazardous Air Pollutants, General Provisions, General control device and work practice requirements for a flare

2 - 81

40 CFR Part 62 Subpart OOO (May 21, 2021)

- Promulgation of a Federal plan to implement the Emission Guidelines (EG) and Compliance Times for Municipal Solid Waste (MSW) Landfills (2016 MSW Landfills EG) for existing MSW landfills located in states and Indian country where state plans or tribal plans are not in effect.
- This MSW Landfills Federal Plan includes the same elements as required for a state plan: Identification of legal authority and mechanisms for implementation; inventory of designated facilities; emissions inventory; emission limits; compliance schedules; a process for the EPA or state review of design plans for site-specific gas collection and control systems (GCCS); testing, monitoring, reporting and record keeping requirements; and public hearing requirements.
- Additionally, this action summarizes implementation and delegation of authority of the MSW Landfills Federal Plan.

2 - 82

40 CFR Part 62 Subpart OOO

- Newly effective Federal Plan Subpart OOO contains provisions for existing "legacy controlled landfills" that already have a GCCS in place (i.e., they are not expected to redo certain specified previously completed compliance obligations), as well as increments of progress for previously uncontrolled existing landfills to meet the requirements (i.e., they are not expected to comply on day one).
- Uncontrolled landfills now subject to Federal Plan Subpart OOO must submit a design capacity report (and an NMOC emissions rate report if the capacity equals or exceeds 2.5 million Mg and 2.5 million cubic meters) by September 20, 2021.
- Future requirements will depend on the NMOC emissions rate; once greater than 34 Mg/year (50 Mg/year for closed landfills), and if surface methane emissions exceed 500 ppm for those choosing to utilize the new Tier 4 option, the landfill will be required to install a GCCS according to specified increments of progress.
- The first increment is due one year after the NMOC emissions rate report in which NMOC emissions equaled or exceeded 34/50 Mg/year, and the last increment (i.e., achieving final compliance) is due 30 months after that report.

2 - 83

40 CFR Part 62 Subpart OOO

- Beginning in 2014, the EPA reviewed the NSPS and EG based on changes in the landfill industry since the rules were first promulgated in 1996, including changes to the size and number of existing landfills, industry practices, and gas control methods and technologies.
- In August 2016, the EPA made several revisions to further reduce emissions of landfill gas (LFG) and its components and promulgated revised subparts for the MSW Landfills NSPS at 40 CFR part 60, subpart XXX, and the EG for existing MSW landfills at 40 CFR part 60, subpart Cf (81 FR 59276 and 59332, August 29, 2016).

2 - 84

40 CFR Part 62 Subpart OOO

- The CAA regulations implementing the EG require states with existing MSW landfills subject to the EG to submit state plans to the EPA in order to implement and enforce the EG.
  State plans implementing the 2016 MSW Landfills EG were due on May 30, 2017.
- For states that did not submit an approvable plan by that deadline, CAA section 111 and 40 CFR 60.27(c) and (d) require the EPA to develop, implement, and enforce a Federal plan for existing MSW landfills located in any state (i.e., state, territory, or protectorate) or Indian country that does not have an approved state plan 2 that implements the 2016 MSW Landfills EG

2 - 85

40 CFR Part 62 Subpart OOO

- Section 111(d) of the CAA, as amended, 42 U.S.C. 7411(d), requires states to develop and implement state plans for MSW landfills to implement and enforce the promulgated EG.
- Accordingly, 40 CFR part 60, subpart Cf requires states to submit state plans that include specified elements.
- Because this Federal plan takes the place of state plans or state plans that are not fully approved and effective, it includes the same essential elements: (1) Identification of legal authority and mechanisms for implementation; (2) inventory of designated facilities; (3) inventory of emissions; (4) emission limits; (5) compliance schedules; (6) process for the EPA or state review of site-specific design plans for GCCS; (7) testing, monitoring, reporting, and recordkeeping requirements; and (8) public hearing requirements.

2 - 86

40 CFR Part 62 Subpart OOO

- This MSW Landfills Federal Plan includes the five increments of progress required by 40 CFR 60.24(e)(1) and provides flexibility to establish the increment dates (40 CFR 62.16712).
- The MSW Landfills Federal Plan contains a generic compliance schedule (Table 1 to 40 CFR part 62, subpart OOO) that applies to designated MSW landfills unless the EPA approves an alternative schedule according to the criteria in 40 CFR 60.27(e)(2)

2 - 87

40 CFR Part 62 Subpart OOO

- The NSPS at 40 CFR part 60, subpart WWW, identified and defined the term ‘‘controlled landfill’’ as one that had triggered the nonmethane organic compounds (NMOC) threshold of 50 Mg per year or more and submitted its collection and control system design plan.
- The provisions of 40 CFR part 60, subpart WWW, require the design plan to be submitted within 1 year of the first NMOC annual emission rate report that is equal to or greater than 50 Mg per year NMOC.
- The EG at 40 CFR part 60, subpart Cc, and the Federal plan at 40 CFR part 62, subpart GGG, do not define the term ‘‘controlled landfill’’ directly but note that the definition of terms used but not defined in those subparts has the meaning given them in the CAA and in 40 CFR part 60, subparts A, B, and WWW.

2 - 88

40 CFR Part 62 Subpart OOO

- These rules provide the same timing allowance of 1 year after the NMOC report showing emissions of 50 Mg NMOC per year or more to submit the collection and control system design plan.
- These landfills have already met requirements under existing 40 CFR part 60 or part 62 regulations, and the EPA emphasizes that there is no need to duplicate those efforts when complying with the Federal plan being finalized in this action.
- The EPA has added a definition of the term ‘‘legacy controlled landfill’’ to 40 CFR 62.16730 to clarify requirements and compliance times for these landfills.

2 - 89

40 CFR Part 62 Subpart OOO

- Legacy controlled landfills have previously satisfied the requirement to submit their initial design capacity report, initial or annual NMOC emission rate reports, and collection and control system design plan.
- These reports were previously submitted under 40 CFR part 60, subpart WWW; 40 CFR part 62, subpart GGG; or a state plan implementing 40 CFR part 60, subpart Cc. The EPA has clarified that it is not requiring these sources to resubmit any of these reports under 40 CFR 62.16711(h).
- Additionally, because annual NMOC reports have been previously submitted under 40 CFR part 60, subpart WWW; 40 CFR part 62, subpart GGG; or a state plan implementing 40 CFR part 60, subpart Cc, some of the <u>legacy controlled landfills</u> have already passed the 30-month period after the first NMOC report that showed emissions of 50 Mg NMOC per year or more.
- Other legacy controlled landfills may not reach the end of the 30-month period until after this Federal plan becomes effective.

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40 CFR Part 62 Subpart OOO

TABLE 1 TO SUBPART OOO OF PART 62—GENERIC COMPLIANCE SCHEDULE AND INCREMENTS OF PROGRESS

Increment	Date if using tiers 1, 2, or 3	Date if using tier 4	Date if a legacy controlled landfill
Increment 1—Submit cover page of final control plan.	1 year after initial NMOC emission rate report or the first annual emission rate report showing NMOC emissions ≥34 megagrams per year.[1].	1 year after the first measured concentration of methane of 500 parts per million or greater from the surface of the landfill.	1 year after the first NMOC emission rate report or the first annual emission rate report showing NMOC emissions ≥50 megagrams per year submitted under a previous regulation.[2]
Increment 2—Award Contracts.	20 months after initial NMOC emission rate report or the first annual emission rate report showing NMOC emissions ≥34 megagrams per year.[1].	20 months after the most recent NMOC emission rate report showing NMOC emissions ≥34 megagrams per year.	20 months after the most recent NMOC emission rate report showing NMOC emissions ≥50 megagrams per year submitted under a previous regulation.[2]
Increment 3—Begin on-site construction.	24 months after initial NMOC emission rate report or the first annual emission rate report showing NMOC emissions ≥34 megagrams per year.[1].	24 months after the most recent NMOC emission rate report showing NMOC emissions ≥34 megagrams per year.	24 months after the most recent NMOC emission rate report showing NMOC emissions ≥50 megagrams per year submitted under a previous regulation.[2]
Increment 4—Complete on-site construction.	30 months after initial NMOC emission rate report or the first annual emission rate report showing NMOC emissions ≥34 megagrams per year.[1].	30 months after the most recent NMOC emission rate report showing NMOC emissions ≥34 megagrams per year.	30 months after the first NMOC emission rate report or the first annual emission rate report showing NMOC emissions ≥50 megagrams submitted under a previous regulation.

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40 CFR Part 62 Subpart OOO

TABLE 1 TO SUBPART OOO OF PART 62—GENERIC COMPLIANCE SCHEDULE AND INCREMENTS OF PROGRESS—Continued

Increment	Date if using tiers 1, 2, or 3	Date if using tier 4	Date if a legacy controlled landfill
Increment 5—Final compliance.	30 months after initial NMOC emission rate report or the first annual emission rate report showing NMOC emissions ≥34 megagrams per year.[1].	30 months after the most recent NMOC emission rate report showing NMOC emissions ≥34 megagrams per year.	30 months after the first NMOC emission rate report or the first annual emission rate report showing NMOC emissions ≥50 megagrams submitted under a previous regulation.[2]

[1] 50 megagrams per year NMOC for the closed landfill subcategory.
[2] Previous regulation refers to 40 CFR part 60, subpart WWW; 40 CFR part 62, subpart GGG; or a state plan implementing 40 CFR part 60, subpart Cc. Increments of progress that have already been completed under previous regulations do not have to be completed again under this subpart.

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EPA Regulation Navigation Tools

Regulation Navigation (Reg Nav) tools help owners and operators of facilities in certain industries determine the requirements of specific air quality regulations. Reg Nav tools are online and interactive, and use the information entered to assess potential regulatory requirements.

Reg Nav tools do not store or save information, so you must print or save any output that you want to use or reference. Note that the Reg Nav requirements may not be complete. Refer any questions to your local authority.

Air Pollutant Category	Regulation	Reg Nav Tool
National Emissions Standards for Hazardous Air Pollutants under 40 CFR part 63	Subpart LLL	Portland Cement Manufacturing Industry
	Subpart AAAA	Municipal Solid Waste Landfills
	Subpart ZZZZ	Reciprocating Internal Combustion Engines (RICE)
	Subpart JJJJJ	Brick and Structural Clay Products Manufacturing
	Subpart HHHHHH	Paint Stripping and Miscellaneous Surface Coating Operations at Area Sources: determining exemption eligibility
	Subpart JJJJJJ	Area Source Industrial, Commercial, and Institutional Boilers
New Source Performance Standards	Subpart WWW	Municipal Solid Waste Landfills
	Subpart XXX	Municipal Solid Waste Landfills That Commenced Construction, Reconstruction, or Modification After July 17, 2014
	Subpart IIII & Subpart JJJJ (one tool)	Stationary Compression Ignition Internal Combustion Engines and Spark Ignition Internal Combustion Engines

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EPA Regulation Navigation Tools | Stationary Sources of Air Pollution | US EPA

Municipal Solid Waste Landfills Monitoring Checklist

EPA United States Environmental Protection Agency

Subpart HH, Greenhouse Gas Reporting Program

What Must Be Monitored for Each MSW Landfill?

Each MSW landfill must monitor these parameters...

- ☐ Annual quantity of waste landfilled (W, in Equation HH-1)
- ☐ For each type of material landfilled, specific waste quantity or fraction, and its associated parameters used to calculate methane generation in Equation HH-1, including: DOC, k, MCF, F, and DOC_f

Each MSW landfill using a gas collection system must also monitor these parameters...

- ☐ Flow rate of landfill gas before any treatment equipment (continuously)
- ☐ Moisture content** of landfill gas (continuously, if available, or monthly*)
- ☐ CH_4 concentration of collected landfill gas (continuously, if available, or monthly*)
- ☐ Annual operating hours where active gas flow was sent to each destruction device)
- ☐ Temperature** of landfill gas (continuously, if available, or monthly*)
- ☐ Annual operating hours of the gas collection system associated with each measurement location
- ☐ Pressure** of landfill gas (continuously, if available, or monthly*)
- ☐ Surface area, average depth of waste, and associated estimated collection efficiencies of areas with the different soil type covers and gas collection system operation listed in Table HH-3

**If only one measurement is made each calendar month, there must be at least fourteen days in between measurements.*

***If the gas flow meter is not equipped with automatic correction for temperature, pressure, or moisture content.*

See also the information sheet for Municipal Solid Waste Landfills (EPA-430-F-09-009R) at: https://www.epa.gov/ghgreporting/subpart-hh-information-sheet.

This document is provided solely for informational purposes. It does not provide legal advice, have legally binding effect, or expressly or implicitly create, expand, or limit any legal rights, obligations, responsibilities, expectations, or benefits in regard to any person. This information is intended to assist reporting facilities/owners in understanding key provisions of the Greenhouse Gas Reporting Program.

Municipal Solid Waste Landfills Monitoring Checklist
Greenhouse Gas Reporting Program
Page 1 of 1

40 CFR, subpart HH
February 2018

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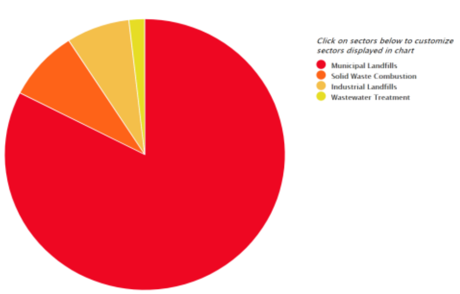
2019 Total Reported Direct Emissions from Waste, by Subsector (as of 9/26/20)

2019 Total Reported Emissions from the Waste Sector, by Subsector



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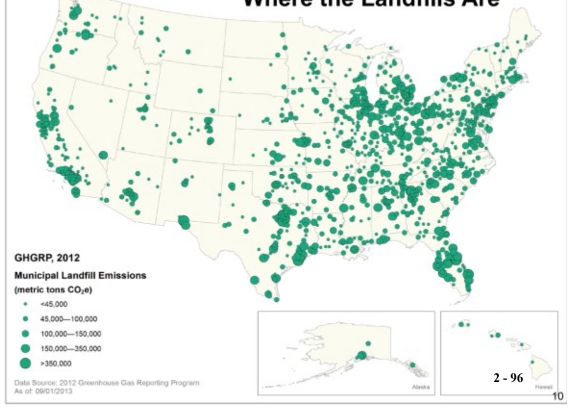
Where the Landfills Are



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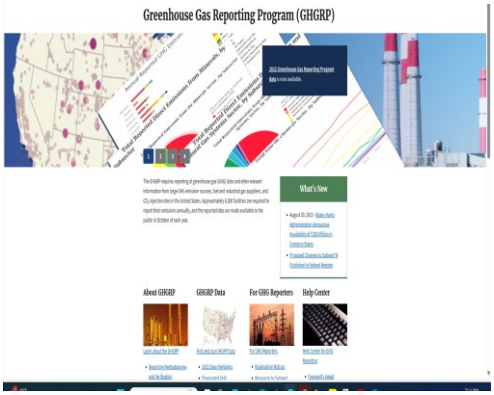

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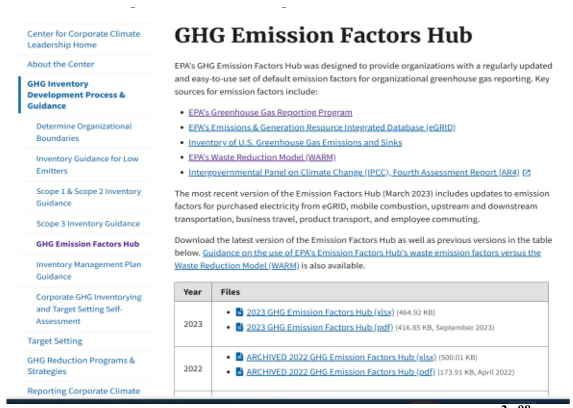
[Greenhouse Gas Reporting Program (GHGRP) | US EPA]



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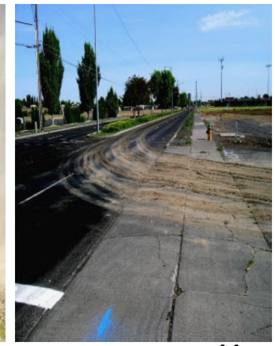
[GHG Reporting Program Data Sets | Greenhouse Gas Reporting Program (GHGRP) | US EP/]

Overview of Specific Landfill Operations Related to Air Quality and Liners

3 - 1

Fugitive Dust and Track-out



3 - 2

WRAP Fugitive Dust Handbook

Prepared for:

Western Governors' Association
1515 Cleveland Place, Suite 200
Denver, Colorado 80202

WRAP_FDHandbook_Rev_06.pdf (nm.gov)

3 - 3

DEQ MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY

Managing Fugitive Dust

A Guide for Compliance with the Air Regulatory Requirements for Particulate Matter Generation

www.michigan.gov/deq | 800-662-9278

Fug-Dust-Man.pdf (michigan.gov)

3 - 4

Fugitive Dust and Track-out Regulations

3 - 5

Building New Sections/Cells at the Landfill

Other Sources of Particulate Matter

Sources of Particulate Matter

Fugitive Dust and Track-out Regulations

- The landfill fugitive dust operations/sources that are covered by permitting and subject to the requirements of OAC rule 3745-31-05 are listed below:
- i. waste dumping/unloading;
- ii. waste compaction;
- iii. soil excavation and handling;
- iv. covering of waste with soil; and
- v. wind erosion from landfill surfaces.

3 - 9

Fugitive Dust and Track-out Regulations

- Work Practice Plan Inspections
- Except as otherwise provided in this section, the permittee shall perform inspections of each of the fugitive dust operations/sources at frequencies described in the Work Practice Plan. The purpose of the inspections is to determine the need for implementing control measures. The inspections shall be performed during representative, normal traffic conditions. No inspection shall be necessary for a fugitive dust operation/source that is covered with snow and/or ice or if precipitation has occurred that is sufficient for that day to ensure compliance with the above-mentioned applicable requirements. Any required inspection that is not performed due to any of the above-identified events shall be performed as soon as such event(s) has (have) ended, except if the next required inspection is within one week. (OAC rule 3745-77-07(C)(1)])

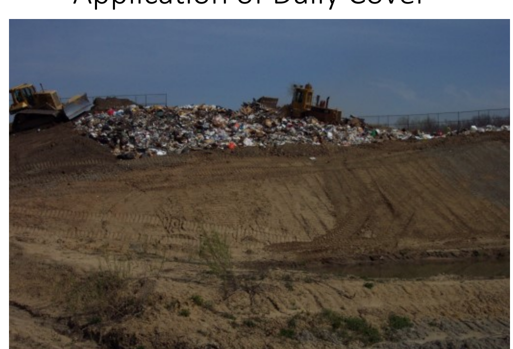
3 - 10

Daily Cover

- The regular application of daily cover soil or an alternative such as tarps or an artificial (alternate daily cover) material is perhaps the most fundamental control on direct effects arising from waste landfilling. Sites with poor daily cover practices are often subject to bird, odor, vermin, litter, and surface water quality problems

3 - 11

Application of Daily Cover



3 - 12

Objectives of Daily cover

- Minimize windblown-litter
- Control odors
- Prevent birds from scavenging
- Prevent un-authorized scavenging by humans
- Prevent infestation by flies and vermin
- Reduce the risk of fire
- Provide a pleasing appearance
- Shed surface water and minimize contamination of runoff generating potential leachate out of the landfill

3 - 13

Types of Daily Cover*

Inert	Waste Derived	Artificial / Synthetic
Free draining soils	Paper pulp	Synthetic foams
Non-draining soils	Pulped paper	Synthetic foams
Contaminated soils	Shredded wood	Plastic film
Foundry sand	Shredded tires	Synthetic mesh
Mine Waste	Shredded plastic	Burlap fabric
Quarry waste	Recycling process waste	Tarps
Ash	Shredded green waste	Foam products
River silts	Pulverized household waste	
	Compost	
	Processed construction and demolition wastes and materials	* ISWA Landfill Operational Guidelines 3rd Edition 2019 and CalRecycle

3 - 14

Advantages And Disadvantages Of Inert Wastes Used As Daily Cover*

Advantages	Disadvantages
Ease of application and availability	Consumes void spaces
Visual appearances	Wheel cleaning often necessary
Non combustible	Potentially dusty
Can be applied using on-site plant	Can be relatively impermeable to leachate and landfill gas
Can be permeable to leachate and landfill gas	Poor traction for certain materials
Good traction quality for some materials	* ISWA Landfill Operational Guidelines 3rd Edition 2019 https://www.iswa.org/home/news/news-detail/article/download-the-3rd-landfill-operations-guidelines/109/

3 - 15

Advantages And Disadvantages of Wastes Derived Materials Used As Daily Cover*

Advantages	Disadvantages
Utilizes a waste stream	Can be ineffective in controlling odors
Permeable to landfill gas and leachate	Processing required
Good running surface	Can attract birds and vermin
Preserves void space for waste	Possible fire hazard
May be biodegradable	Dust can be a problem particularly from shredded wood
	* ISWA Landfill Operational Guidelines 3rd Edition 2019

3 - 16

Advantages And Disadvantages Of Artificial/Synthetic Materials Used As Daily Cover*

Advantages	Disadvantages
Useful on incline surfaces	May not suppress odors
Readily deployed with modifications to existing plant	May not prevent fly infestation
Saves void spaces	Potential fire risk
Permeable to landfill gas and leachate and biodegradable	Useful as daily cover only
Good visual apperance	Cost
	Not suitable for trafficked areas
	Color
	Difficult to apply under adverse weather conditions
* ISWA Landfill Operational Guidelines 3rd Edition 2019	Difficult to apply progressively during the working day

3 - 17

Bird Control

3 - 18

Bird Control

All birds have three key habit drivers:

- food supply, rest and the ability of breeding.

Landfill sites can offer a suitable environment for these, depending on the type of bird.

- Birds visit landfills mainly for food. They can be noisy and leave droppings not just at the landfill, but on neighboring roofs, gardens and open spaces.
- They can also be carriers of pathogens, will increase their breeding if given a dependable food supply and will come from greater distances form the landfill.

3 - 19

Bird Control

3 - 20

Bird Control*

Controlling birds need to account for that birds can:

- Quickly become accustomed to the usual methods of bird control that are used.
- Control methods should be varied, as required, to provide an effective control strategy.
- If birds can be identified by species it is often possible to use their instinctive and learned behaviour against them to minimize their level of nuisance.

* ISWA Landfill Operational Guidelines 3rd Edition 2019

3 - 21

Hierarchy Bird Control

3 - 22

Hierarchy Of Controls

- Operational Practices
- Gas Guns
- Heli-kites and Balloons
- Distress Calls
- Signal Pistols and Cartridges
- Falcons and Raptors
- Wires and Screens
- Culling

- ISWA Landfill Operational Guidelines 3rd Edition 2019

3 - 23

Challenges of Litter Control

WSAW-TV Photo

https://www.wsaw.com/content/news/Garbage-from-landfill-blown-into-neighborhoods-415735603.html

Garbage from landfill blown into neighborhoods | WLUK (fox11online.com)

3 - 24

Challenges of Litter Control (cont.)

- Traditional MSW landfills can produce litter. Two things are required for litter to blow: wind and debris. Liter materials such as paper, plastic shopping bags or dry-cleaner plastic bags, require very little wind and can move considerable distance even with light winds. As the wind velocity increases, greater volumes and range of materials can become airborne.

3 - 25

Challenges of Litter Control (cont.)

- To be effective, litter control strategies should include both engineering solutions and management options.
Litter at landfill sites is largely associated with delivery and unloading of waste rather than with compaction and burial operations, as the compaction and burial process generally punctures the plastic bags and covers the waste material making bags less likely to become windblown.

The Science and Technology of Landfill Litter Control on Vimeo

3 - 26

Litter Control Methods*

- Load control
- Waste handling
- Portable litter screens
- Semi-permanent litter fencing
- Embankments
- Perimeter fencing
- Select tipping areas
- Netted areas
- Designated waste transfer areas
- Methods for handling for lightweight waste
- Restricting operating hours

* ISWA Landfill Operational Guidelines 3rd Edition 2019

3 - 27

Landfill Odors and Controls

- People in communities near landfills are often concerned about odors emitted from landfills. They say that these odors are a source of undesirable health effects or symptoms, such as headaches and nausea.
- Landfill gas odors are produced by bacterial or chemical processes and can emanate from both active or closed landfills.
- These odors can migrate to the surrounding community. Potential sources of landfill odors include sulfides, ammonia, and certain NMOCs, if present at concentrations that are high enough.

3 - 28

Other Operational Considerations

- Site Roads
- Pest Control
- Waste Compaction
- Stormwater and Sediment Control
- Leachate Control and Treatment
- Odor Control
- Landfill Gas Management
- Site Health Safety and Security
- Landfill Monitoring
- Community Affairs

3 - 29

Liquids On Top Of Scrim Tarp And Gas Pillows

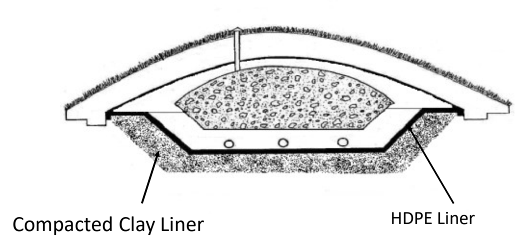
3 - 30

Missouri Superfund Landfill Site

West Lake Landfill - Wikipedia

3 - 31

Landfill Liner



3 - 32

Landfill Liners

Purposes

- To prevent leachate from seeping into groundwater
- To prevent landfill gas from migrating out of the landfill below grade
- To prevent leachate from seeping into groundwater
- To prevent landfill gas from migrating out of the landfill below grade

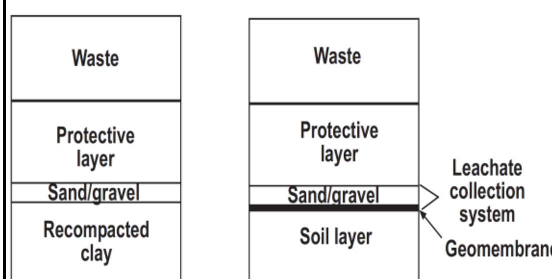
Typical Materials

- 3-foot layer of compacted soil, underlying
- 60-mil high density polyethylene (HDPE)

3 - 33

Landfill Types and Liner Systems

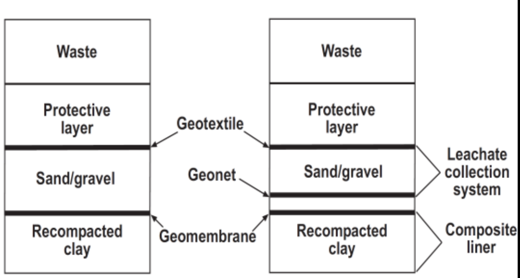
- **Single-Liner Systems**



3 - 34

Landfill Types and Liner Systems

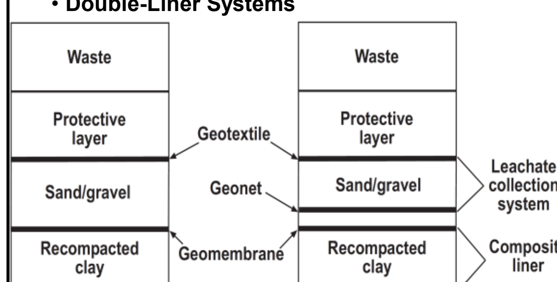
- **Composite-Liner Systems**



3 - 35

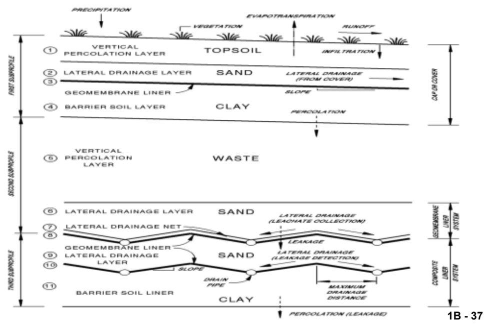
Landfill Types and Liner Systems

- **Double-Liner Systems**



3 - 36

Schematic Profile View of a Typical Hazardous Waste Landfill



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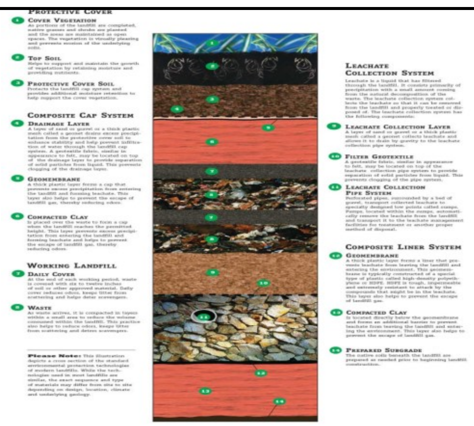
Liner Components

- **Clay:** To protect the ground water from landfill contaminants, clay liners are constructed as a simple liner that is two- to five-feet thick.
- **Geomembranes:** Geomembranes are also called flexible membrane liners (FML). These liners are constructed from various plastic materials, including polyvinyl chloride (PVC) and high-density polyethylene (HDPE).
- **Geotextiles:** In landfill liners, geotextiles are used to prevent the movement of small soil and refuse particles into the leachate collection layers and to protect geomembranes from punctures. These materials allow the movement of water but trap particles to reduce clogging in the leachate collection system.
- **Geosynthetic Clay Liner (GCL):** Geosynthetic consist of a thin clay layer (four to six millimeters) between two layers of a geotextile.
- **Geonet:** A geonet is a plastic net-like drainage blanket which may be used in landfill liners in place of sand or gravel for the leachate collection layer

3 - 38



3 - 39

Leachate Collection Systems

- Integrated into all liner systems is a leachate collection system. This collection system is composed of sand and gravel or a *geonet.*
- A geonet is a plastic net-like drainage blanket. In this layer is a series of leachate collection pipes to drain the leachate from the landfill to holding tanks for storage and eventual treatment.
- In double-liner systems, the upper drainage layer is the leachate collection system, and the lower drainage layer is the leak detection system.
- The leak detection layer contains a second set of drainage pipes. The presence of leachate in these pipes serves to alert landfill management if the primary liner has a leak.

3 - 40

Asbestos Disposal Overview

FedCenter - Asbestos Landfills

3 - 41

61.154 Standard for active waste disposal sites.

eCFR :: 40 CFR 61.154 -- Standard for active waste disposal sites.

3 - 42

Standard for active waste disposal sites

- (a) Either there must be no visible emissions to the outside air from any active waste disposal site where asbestos-containing waste material has been deposited, or the requirements of paragraph (c) or (d) of this section must be met.
- (b) Unless a natural barrier adequately deters access by the general public, either warning signs and fencing must be installed and maintained as follows, or the requirements of paragraph (c)(1) of this section must be met.
- (1) Warning signs must be displayed at all entrances and at intervals of 100 m (330 ft) or less along the property line of the site or along the perimeter of the sections of the site where asbestos-containing waste material is deposited

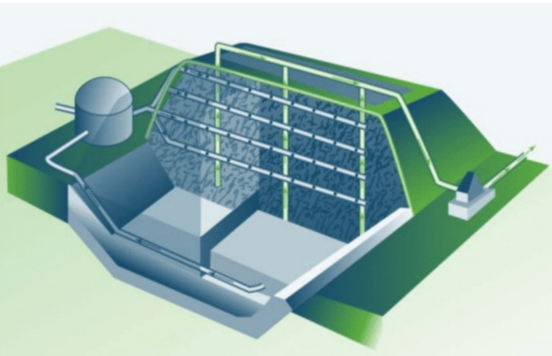
3 - 43

Standard for active waste disposal sites

- Maintain waste shipment records, using a form similar to that shown in Figure 4, and include the following information:
- (i) The name, address, and telephone number of the waste generator.
- (ii) The name, address, and telephone number of the transporter(s).
- (iii) The quantity of the asbestos-containing waste material in cubic meters (cubic yards).
- (iv) The presence of improperly enclosed or uncovered waste, or any asbestos-containing waste material not sealed in leak-tight containers. Report in writing to the local, State, or EPA Regional office responsible for administering the asbestos NESHAP program for the waste generator (identified in the waste shipment record), and, if different, the local, State, or EPA Regional office responsible for administering the asbestos NESHAP program for the disposal site, by the following working day, the presence of a significant amount of improperly enclosed or uncovered waste. Submit a copy of the waste shipment record along with the report.
- (v) The date of the receipt.

3 - 44

Bioreactor Landfills



Bioreactor Landfills | US EPA

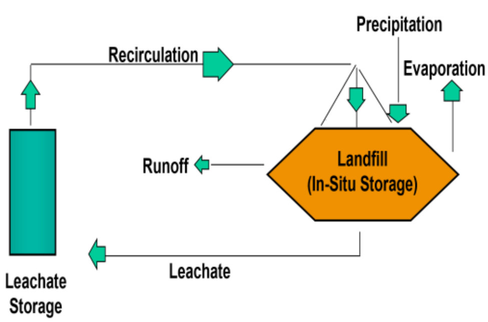
4 - 1

Bioreactor Landfills

- "Bioreactors are landfills where controlled addition of non-hazardous liquid wastes or water accelerates the decomposition of waste and landfill gas generation." (US EPA Office of Research and Development's definition)
- USEPA MACT Rule • "Any landfill or portion of a landfill where liquid other than leachate is added in a controlled fashion into the waste mass (often in combination with recirculation of leachate) to reach a minimum of 40% by weight."
- Requires installation of gas control and collection system prior to liquid addition
- Operate gas control within 180 days after achieving moisture of 40%.
- Bioreactor is closed, liquid addition ceased for one year or more
- Can remove or stop control when EG/NSPS (Emission Guidelines/New Source Performance Standards) are met

4 - 2

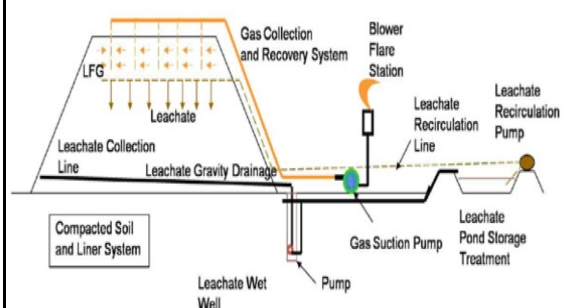
Bioreactor Landfills



Waste Management Technology Center, Inc.

4 - 3

Bioreactor Landfills



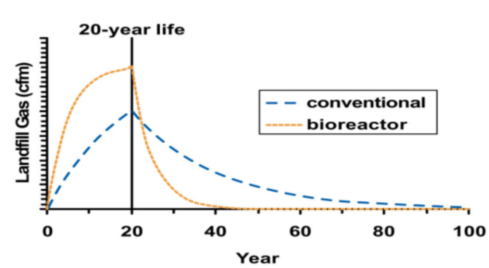
4 - 4

Bioreactor Landfills

- A bioreactor landfill operates to rapidly transform and degrade organic waste.
- The increase in waste degradation and stabilization is accomplished through the addition of liquid and air to enhance microbial processes.
- This bioreactor concept differs from the traditional "dry tomb" municipal landfill approach.

4 - 5

Modeled Behavior of Conventional and Bioreactor Landfills



4 - 6

Bioreactor Landfill Features

- The bioreactor accelerates the decomposition and stabilization of waste.
- Leachate is injected into the bioreactor to stimulate the natural biodegradation process and often need other liquids such as stormwater, wastewater, and wastewater treatment plant sludges to supplement leachate to enhance the microbiological process by purposeful control of the moisture content and differs from a landfill that simple recirculates leachate for liquids management.
- Moisture content is the single most important factor that promotes the accelerated decomposition.
- The bioreactor technology relies on maintaining optimal moisture content near field capacity (approximately 35 to 65%) and adds liquids when it is necessary to maintain that percentage.

4 - 7

Bioreactor Landfill Features

- The moisture content, combined with the biological action of naturally occurring microbes decomposes the waste.
- The microbes can be either aerobic or anaerobic.
- A side effect of the bioreactor is that it produces landfill gas (LFG) such as methane in an anaerobic unit at an earlier stage in the landfill's life and at an overall much higher rate of generation than traditional landfills.

4 - 8

Bioreactor Landfills

There are three different general types of bioreactor landfill configurations:

- Aerobic -
- Anaerobic -
- Hybrid

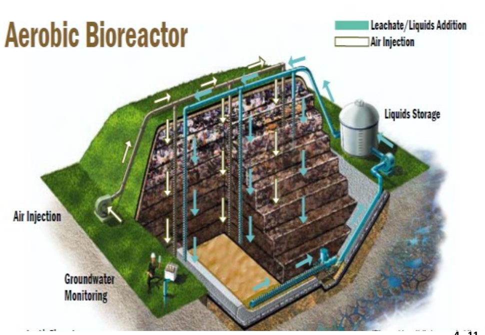
4 - 9

Aerobic bioreactor landfill

- **Aerobic** - In an aerobic bioreactor landfill, leachate is removed from the bottom layer, piped to liquids storage tanks, and re-circulated into the landfill in a controlled manner. Air is injected into the waste mass, using vertical or horizontal wells, to promote aerobic activity and accelerate waste stabilization. http://www.epa.gov/epaoswer/non-hw/muncpl/landfill/bioreactors.htm

4 - 10

Aerobic Bioreactor Landfill



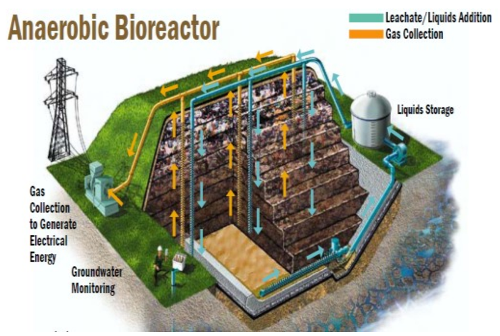
4 - 11

Anaerobic Bioreactor Landfill

- **Anaerobic** - In an anaerobic bioreactor landfill, moisture is added to the waste mass in the form of re-circulated leachate and other sources to obtain optimal moisture levels. Biodegradation occurs in the absence of oxygen (anaerobically) and produces primarily methane.

4 - 12

Anaerobic Bioreactor Landfill



4 - 13

Hybrid Bioreactor Landfill

- **Hybrid** (Aerobic-Anaerobic) - The hybrid bioreactor landfill accelerates waste degradation by employing a sequential aerobic-anaerobic treatment to rapidly degrade organics in the upper sections of the landfill and collect gas from lower sections. Operation as a hybrid results in the earlier onset of methanogenesis compared to aerobic landfill

4 - 14

4 - 15

Table 1
Comparison of landfill scenarios.

Landfill type	Landfill definition	Potential monetary benefits	Operation and maintenance	Leachate volume reduction	Air injection costs	Methane utilization for electricity generation	Closure and post-closure care	Airspace recovery
Traditional	Operated with intent of entombing waste	Utilization of methane for electricity generation	Typical costs (Table 3)	None	None	Gas collection begins in year 6, after closure. Gas generation parameters: L_o = 100 m^3 CH_4/Mg K = 0.04/year	Typical costs (Table 4)	None
Anaerobic retrofit bioreactor	Bioreactor operation commences following active filling (year 6)	Leachate treatment savings; utilization of methane for electricity; airspace recovery	Typical costs	Yes, but begins in year 6. Only leachate not recirculated requires treatment. The landfill reaches field capacity in year 9	None	Gas collection begins in year 6, after closure. Gas generation parameters: Pre-Field Capacity: L_o = 100 m^3 CH_4/Mg K = 0.04/year Post-Filed Capacity: L_o = 100 m^3 CH_4/Mg K = 0.15/year	A temporary final cap is installed at the end of the active filling period. The final cap is constructed at the end of year 15. Bioreactor O&M costs are incurred during the PCC period	Yes. All space is regained at the end of the bioreactor period (year 15) and prior to installation of a final cap
Anaerobic as-built bioreactor	Bioreactor operation commences during active filling.	Leachate treatment savings; utilization of methane for electricity; airspace recovery	In addition to typical costs, leachate recirculation costs are incurred	Yes. Begins immediately	None	Gas collection begins in year 1 (although the capture efficiency is low). L_o = 100 m^3 CH_4/Mg K = 0.15/year	A temporary final cap is installed at the end of the active filling period. The final cap is constructed at the end of year 10. Bioreactor O&M costs are incurred during the PCC period.	Yes. All space is regained in real-time. In addition, cost savings associated with the deferment of the next cell construction is realized
Retrofit hybrid bioreactor	Bioreactor operation commences following active filling (year 6). Air injection occurs for periods ranging between 0.25 and 5 years	Leachate treatment savings; utilization of methane for electricity; airspace recovery	In addition to typical costs, leachate recirculation and air injection costs are incurred	Yes, but begins in year 6. Only leachate not recirculated requires treatment. The landfill reaches field capacity in year 9. During air injection, 50% of the leachate produced is evaporated	Yes. Electricity and O&M costs associated with air blowers and the injection system are incurred during PCC	Gas collection begins subsequent to active filling and air injection. Gas generation parameters: Pre-field capacity: L_o = 100 m^3 CH_4/Mg K = 0.04/year Post-field capacity: L_o = 100 m^3 CH_4/Mg K = 0.15/year	A temporary final cap is installed at the end of the active filling period. The final cap is constructed at the end of year 10. Bioreactor O&M costs are incurred during the PCC period	Yes. All space is regained at the end of the bioreactor period (year 15) and prior to installation of a final cap
As-built hybrid bioreactor	Bioreactor operation commences during active filling. Air injection occurs for periods ranging between 0.25 and 5 years	Leachate treatment savings; utilization of methane for electricity; airspace recovery	In addition to typical costs, leachate recirculation and air injection costs are incurred	Yes. Begins immediately. Only leachate not recirculated requires treatment. The landfill reaches field capacity in year 3. During air injection, 50% of the leachate produced is evaporated	Yes. Electricity and O&M costs associated with air blowers and the injection system are incurred during PCC	Gas collection begins in year 1 (although the capture efficiency is low), but subsequent to air injection Pre-field capacity: L_o = 100 m^3 CH_4/Mg K = 0.04/year Post-Field Capacity: L_o = 100 m^3 CH_4/Mg K = 0.15/year	A temporary final cap is installed at the end of the active filling period. The final cap is constructed at the end of year 10. Bioreactor O&M costs are incurred during the PCC period	Yes. All space is regained in real-time. In addition, cost savings associated with the deferment of the next cell construction is realized
Aerobic bioreactor	Bioreactor operation commences during active filling. Air injection occurs immediately and continues during entire bioreactor period	Leachate treatment savings; utilization of methane for electricity; airspace recovery	In addition to typical costs, leachate recirculation and air injection costs are incurred	Yes. Begins immediately. Only leachate not recirculated requires treatment. The landfill reaches field capacity in year 3. During air injection, 50% of the leachate produced is evaporated	Yes. Electricity and O&M costs associated with air blowers and the injection system are incurred during PCC	No gas is collected for electricity generation	A temporary final cap is installed at the end of the active filling period. The final cap is constructed at the end of year 10. Bioreactor O&M costs are incurred during the PCC period	Yes. All space is regained in real-time. In addition, cost savings associated with the deferment of the next cell construction is realized

N.D. Berge et al. / Waste Management 29 (2009) 1558–1567

Bioreactor Landfills in the United States: An Overview | Geoengineer.org

4 - 16

Project XL Bioreactor Landfill Pilots

- Project XL (eXcellence and Leadership) was an EPA initiative that began in 1995.
- The program provides limited regulatory flexibility for regulated entities to conduct pilot projects that demonstrate the ability to achieve superior environmental performance.
- The information and lessons learned from Project XL are being used to assist EPA in redesigning its current regulatory and policy-setting approaches. As of September 2001, 51 pilot experiments were implemented.
- The landfill pilot projects included:
- Buncombe County Landfill Project, North Carolina
- Day in the Life :: Landfill - YouTube
- Maplewood Landfill and King George County Landfills, Virginia
- Yolo County Bioreactor Landfill, California

4 - 17

Collected Data from Bioreactors for Benefits Determination

- Alternative liner design/materials for leachate re-circulation and bioreactor landfills
- Physical stability of the cover and bottom liner during and after operation
- Impacts of leachate quality, quantity, and loading on the liner system
- Times and amounts of liquids it takes to reach field capacity
- Appropriate means for measuring field capacity
- Leachate re-circulation and its affect on the rate and extent of landfill stabilization
- Stabilization measures
- Design, operation, and performance specifications for bioreactors
- Rate, quantity, and quality of gas generation
- Interim covers used after placement to accommodate anticipated settlement
- Daily and final cover performance
- Optimum moisture content and distribution methods
- Monitoring requirements
- Bioreactor technology impacts on capping, and current closure and post -closure requirements

4 - 18

Potential Advantages of Bioreactor Landfills

- Decomposition and biological stabilization of the waste in a bioreactor landfill can occur in a much shorter time frame than occurs in a traditional "dry tomb" landfill providing a potential decrease in long-term environmental risks and landfill operating and post-closure costs. Potential advantages of bioreactors include:
- Decomposition and biological stabilization in years vs. decades in "dry tombs"
- Lower waste toxicity and mobility due to both aerobic and anaerobic conditions
- Reduced leachate disposal costs
- A 15 to 30 percent gain in landfill space due to an increase in density of waste mass
- Significant increased LFG generation that, when captured, can be used for energy use onsite or sold
- Reduced post-closure care

4 - 19

Special Considerations of Bioreactor Landfills

- Bioreactor landfills generally are engineered systems that have higher initial capital costs and require additional monitoring and control during their operating life, but are expected to involve less monitoring over the duration of the post-closure period than conventional "dry tomb" landfills. Issues that need to be addressed during both design and operation of a bioreactor landfill include:
- Increased gas emissions
- Increased odors
- Physical instability of waste mass due to increased moisture and density
- Instability of liner systems
- Surface seeps
- Landfill fires

4 - 20

Landfill Gas Extraction: Issues and Strategies

- **Increased Atmospheric Emissions:** Generally, leachate recirculation and other forms of liquid addition are practiced during the operational years of the landfill.
- Leachate production is greatest during this period and it is the only time when certain types of liquid addition system may be utilized (e.g., direct application to the working face using tankers or spray system). The operating years of a landfill cell's life are also the time when gas collection efficiency may be at its lowest.
- Bioreactor landfill operators must control and collect gas sooner than conventional landfills, or else atmospheric emissions will be increased. In addition to regulatory problems and general environmental concerns, this cause operational issues because of odor
- **Increased Gas Collection Capacity**: The capacity of the gas collection and conveyance system will need to be greater than a similar size conventional landfill (e.g., larger pipe diameter).
- Since many bioreactor landfill operators will practice liquids addition during the operational life of the landfill prior to closure, the approach for gas collection may need to be different than typical vertical well extraction systems at conventional landfills. The additional amount of condensate should also be considered in the design.

4 - 21

Landfill Gas Extraction: Issues and Strategies

- **Liquids in Gas Collection Lines**: The difficultly with traditional gas collection devices at bioreactor landfills is that they tend to fill with liquids. Liquid and gas inside a landfill will follow the path of least resistance. If a gas collection device intercepts part of a saturated zone, liquids from this zone can migrate into the device.
- This problem has been observed for both vertical wells and horizontal trenches. The presence of moisture greatly reduces the ability of gas to move through the waste. If the waste surrounding a gas collection device is flooded, even if large amounts of gas are produced, gas will move elsewhere to a path wit less resistance.

4 - 22

Landfill Gas Extraction: Issues and Strategies

Methods of Gas Collection by Different Strategies	
Dewatering Pumps	Special dewatering pumps are available that can be added to gas extraction devices to remove the liquids. These are often used at landfills in wet climates that do not practice liquids addition.
Leachate Recirculation Devices for Gas Extraction	Newer horizontal leachate injection lines can be used for gas collection. Experience has found that once liquids are added to a trench in large amounts, gas collection becomes difficult.
Leachate Collection System	Gas may be collected from the leachate collection system, Path of least resistance, gas produced in the bottom of the landfill will migrate downward. Many landfills have successfully incorporated gas collection from the leachate collection system.
Surface Caps	Horizontal trenches on the surface of the waste but under the exposed geomembrane cap (EGC) may be used for gas collection. A toe drain should be installed around the perimeter of the landfill to intercept seeps underneath the EGC and to route the liquids to leachate collection system.

4 - 23

BIOREACTOR LANDFILL OPERATION

A Guide For Development, Implementation and Monitoring

Version 1.0 (July 1, 2008)

Developed under Funding from:
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and
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EPA United States Environmental Protection Agency — 600R04301

Monitoring Approaches for Landfill Bioreactors

30006HMR.PDF (epa.gov)

CLU-IN | Technologies > Remediation > About Remediation Technologies > Bioreactor Landfills > Guidance (clu-in.org)

4 - 25

Project XL

- Since promulgation of Subtitle D in 1991, a growing number of landfill sites have practiced leachate recirculation as well as addition of bulk free liquids, generally under ad hoc state-level research and development programs (e.g., the Florida Bioreactor Demonstration Project) or site-specific permitting mechanisms administered in association with EPA (e.g., Project XL). The main premise behind bioreactor landfills is the controlled introduction of moisture into the solid waste mass to increase the waste degradation rate.

4 - 26

Project XL

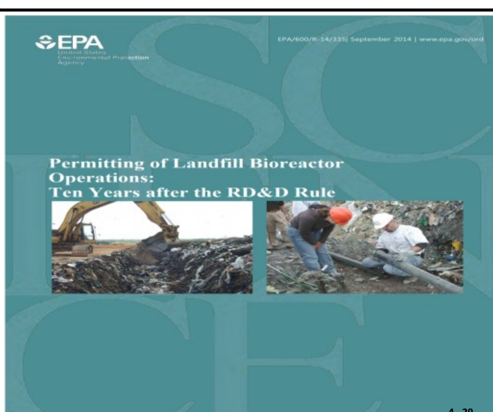
- Project XL (i.e., eXcellence and Leadership) is an EPA initiative, which began in 1995.
- The program provides limited regulatory flexibility for regulated entities to conduct pilot projects that demonstrate the ability to achieve superior environmental performance. The information and lessons learned from Project XL are being used to assist EPA in redesigning its current regulatory and policy-setting approaches.
- As of September 2001, 51 pilot experiments have been implemented. Of those being implemented in this innovative program, four landfill pilot projects have been approved to operate as bioreactors. These landfill pilot projects include the following locations:
- Buncombe County Landfill Project, North Carolina
- Maplewood Landfill and King George County Landfills, Virginia
- Yolo County Bioreactor Landfill, California

4 - 27

Project XL

- To formally promote innovative landfill technologies, including adoption of alternative cover systems and bioreactor technology, the EPA published the Research, Development, and Demonstration (RD&D) Permit Rule (the Rule) on March 22, 2004. The Rule allows Subtitle D landfills a variance option for adding bulk free liquids if a demonstration can be made that such a variance will not increase risk to human health and the environment relative to standard permit conditions for the landfill.

4 - 28



4 - 29

NESHAP AAAA and Bioreactor Requirements

- In addition, the NESHAP requires bioreactor is an MSW landfill or portion of the landfill where any liquid other than leachate is added to the waste mass to reach a minimum average moisture content of at least 40 percent by weight to accelerate or enhance the biodegradation of the waste.
- New bioreactors must install the GCCS in the bioreactor prior to initiating liquids addition, regardless of whether the landfill emissions rate equals or exceeds the estimated uncontrolled emissions rate; existing bioreactors must install the GCCS before initiating liquids addition and must begin operating the GCCS within 180 days after initiating liquids addition or within 180 days after achieving a moisture content of 40 percent by weight, whichever is later.

4 - 30

NESHAP AAAA and Bioreactor Requirements

- The EPA is requiring owners and operators of new or modified MSW landfills to electronically submit required performance test reports, NMOC Emission Rate Reports,
- Bioreactor 40-percent moisture reports, and semi-annual reports through the EPA's Central Data Exchange (CDX) using the Compliance and Emissions Data Reporting Interface (CEDRI) (40 CFR 63.1981(l)).
- The final rule requires that performance test results be submitted using the Electronic Reporting Tool (ERT).
- For NMOC Emission Rate Reports, Bioreactor 40-percent moisture reports, and semiannual reports, the final rule requires that owners and operators use the appropriate spreadsheet template/forms to submit information to CEDRI when it becomes available on the CEDRI website.

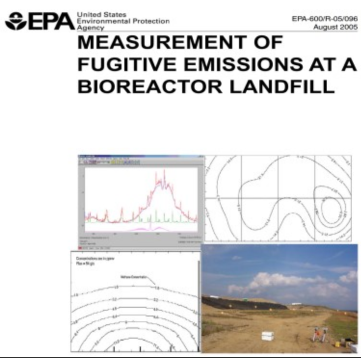
4 - 31

NESHAP AAAA and Bioreactor Requirements

- Owners or operators are no longer required to comply with the requirements of this subpart for the bioreactor provided you meet the conditions of either paragraph (a) or (b) of this section if
- (a) the affected source meets the control system removal criteria in § 63.1950 or the bioreactor meets the criteria for a nonproductive area of the landfill in § 63.1962(a)(3)(ii).
- (b) The bioreactor portion of the landfill is a closed landfill as defined in § 63.1990, or permanently ceased adding liquids to the bioreactor, and you have not added liquids to the bioreactor for at least 1 year. A closure report for the bioreactor must be submitted to the Administrator as provided in § 63.1981(g).

4 - 32

Air Emissions From a Bioreactor Landfills



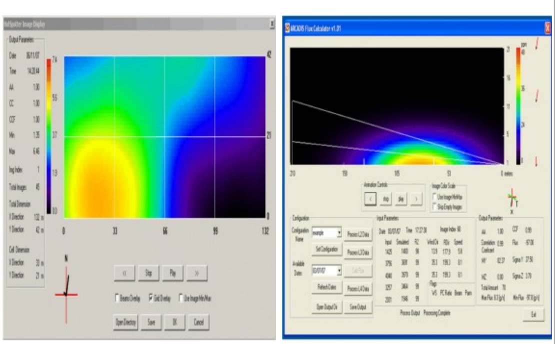
4 - 33

Air Emissions From a Bioreactor Landfills

- The data presented in this report are from three field campaigns performed during September 2002, May 2003, and September 2003 by ARCADIS and the United States Environmental Protection Agency (U.S. EPA) to measure fugitive emissions at a bioreactor landfill in Louisville, Kentucky, using an open-path Fourier transform infrared (OP-FTIR) spectrometer.
- The study involved a technique developed through research funded by U.S. EPA's National Risk Management Research Laboratory (NRMRL) that uses optical remote sensing-radial plume mapping (ORS-RPM). The horizontal radial plume mapping (HRPM) method was used to map surface concentrations, and the vertical radial plume mapping (VRPM) method was used to measure emissions fluxes downwind of the site.
- Surveys were conducted in five areas at the Louisville facility: As-Built (an area designed as a bioreactor landfill), Retrofit (an area converted to a bioreactor landfill), Control, Bio-cover, and Compost.

4 - 34

Horizontal and Vertical RPM Output From Software



Air Emissions From a Bioreactor Landfills Study

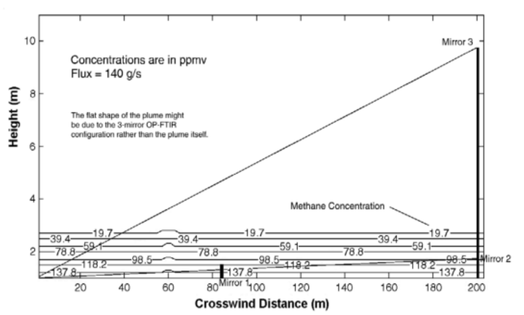
Table 1. DQI Goals for Critical Measurements

Measurement Parameter	Analysis Method	Accuracy	Precision	Detection Limit	Completeness
Analyte PIC	OP-FTIR	±5%	±10%	see Table 2	90%
Ambient Wind Speed	Climatronics Met heads side-by-side comparison in the field	±1 m/s	±1 m/s		90%
Ambient Wind Direction	Climatronics Met heads side-by-side comparison in the field	±10°	±10°		90%
Distance Measurement	Theodolite- Topcon	±1 m	±1 m	0.1 m	100%
Elemental Mercury	Lumex (direct method)	±20%	±20%	2 – 500 ng/m^3 [e]	90%
Total Mercury[a]	TD-GC-AFS[c]	50–150% recovery	±20%	33 ng/m^3 [f]	90%
Dimethyl Mercury (Carbotrap)[a]	TD-GC-pyrolysis-CVAFS[d]	50–150%	±20%	1.1 ng/m^3 [g]	90%
Monomethyl Mercury[a]	TD-GC-CVAFS	50–150%	±20%	0.63 ng/m^3 [h]	90%
Total Mercury[b]	TD-GC-AFS	50–150%	±20%	33 ng/m^3 [f]	90%
Dimethyl Mercury (Carbotrap)[b]	TD-GC-pyrolysis-CVAFS	50–150%	±20%	19.8 ng/m^3 [i]	90%
Dimethyl Mercury (methanol)[b]	TD-GC-CVAFS	50–150%	±20%	0.34 ng/m^3 [f]	90%
Monomethyl Mercury[b]	TD-GC-CVAFS	50–150%	±20%	0.34 ng/m^3 [f]	90%

[a] September 2002 campaign.
[b] September 2003 campaign.
[c] TD = thermal desorption; GC = gas chromatography; AFS = atomic fluorescence spectrometry.
[d] CVAFS = cold vapor atomic fluorescence spectrometry.
[e] Estimated detection limit for natural and industrial gases. The landfill gas would have to be assayed to determine the actual detection limit of the instrument.
[f] Estimated detection limit for a 30 L sample.
[g] Estimated detection limit for a 9.0 L sample.
[h] Estimated detection limit for a 16.0 L sample.
[i] Estimated detection limit for a 0.5 L sample.
All of the detection limits listed for the Frontier methods are method limits, which are essentially 10× the detection limit.

4 - 36

Average Reconstructed Methane Plume from the September 2003 Upwind As-Built Lower VRPM Survey



4 - 37

Estimated NMOC Flux Values from the Control and Bioreactor Cells of Site in Florida

Compound	Corrected Landfill Gas Concentration (ppbv)	Estimated Flux Value from Control Cell (grams per day)	Estimated Flux Value from Bioreactor Cell (grams per day)
Dichlorodifluoromethane (Freon 12)	143.8	3.4	8.7
1,2-Chloro-1,1,2,2-Tetrafluoroethane	17.6	0.60	1.5
Vinyl chloride	41.2	0.51	1.3
Bromomethane	1.8	0.030	0.090
Trichloromonofluoromethane	4.8	0.13	0.33
Carbon disulfide	34.4	0.52	1.3
Isopropyl alcohol	820.8	9.7	25
Methylene chloride	140.1	2.4	6.0
Acetone	1793	21	52
Hexane	107.8	1.8	4.7
Methyl-t-butyl ether (MTBE)	1.3	0.020	0.060
Vinyl acetate	47.5	0.81	2.1
cis-1,2-dichloroethene	35.2	0.68	1.7
Cyclohexane	105.8	1.8	4.5
Chloroform	32.4	0.76	1.9
Ethyl Acetate	538.3	9.4	24
Tetrahydrofuran	341.3	4.9	12
2-Butanone	1501	21	54
Benzene	293.8	4.5	11
Trichloroethylene	36.7	0.95	2.4
Toluene	2852	52	130
4-Methyl-2-pentanone (MIBK)	183.3	3.6	9.2
Tetrachloroethylene	18.0	0.59	1.5
Ethylbenzene	2186	46	120
m/p-Xylene	4049	85	220
o-Xylene	1122	24	60
Styrene	114.1	2.4	6.0
Tribromomethane	9.1	0.46	1.2

4 - 38

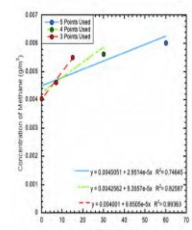
Average Concentrations of Total, Dimethyl, and Monomethyl Mercury Found in the Bioreactor, Control Cell, and Flare Gas During the September 2003 Field Campaign

Compound	Retrofit Area/Unit 5 (ng/m³)	As-Built (ng/m³)	Control Area/ Units 73A and 74a (ng/m³)	Flare Gas (ng/m³)
Total Hg	237	334	2803	986
DMHg[a] (carbotrap)	22.1	128	71.5	26.7
DMHg (methanol)	47.4	363	66.8	58
MMHg[b]	2.03	0.55	0.66	1.67

[a] DMHg = dimethyl mercury.
[b] MMHg = monomethly mercury.

4 - 39

Flux determined using concentration measurements over time



$$F = \frac{dC}{dt} * \frac{V}{A}$$

F: surface flux
dC/dt: concentration gradient (the rate of change of concentration over time within the flux chamber)
V: volume within the static flux chamber
A: area of the landfill surface enclosed by the chamber

lfg-emissions-ppt-calpoly-16isd006.pdf

4 - 40

Buncombe County Solid Waste Management - Bioreactor

Day in the Life

- Day in the Life :: Landfill - YouTube

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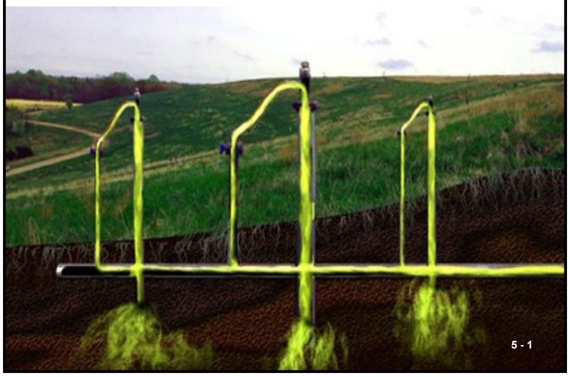
Landfill Gas (LFG) and Constituents



5 - 1

Why Did The Landfill Gas Cross The Road?

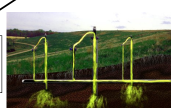
- **Gas is lazy.**
  It always follows the path of least resistance.

5 - 2

Landfill Gas Emission Sources

Total gas generated

Gas collection system



Uncollected gas Landfill surface (cover, fissures, around wells, etc.)

Treatment devices (flare, gas-to-energy

Migration out of waste boundary on and off site?

5 - 3

Landfill Gas (LFG)– What Is It?

- **Gaseous by-product of decomposition of organic materials in landfills under anaerobic conditions. Landfill gas is produced as a result of a sequence of physical, chemical, and biological processes occurring within an anaerobic landfill.**

5 - 4

What is landfill gas composed of?

- **Landfill gas is composed of a mixture of hundreds of different gases.**
- **By volume, landfill gas typically contains 45% to 60% methane and 40% to 60% carbon dioxide. Landfill gas also includes small amounts of nitrogen, oxygen, ammonia, sulfides, hydrogen, carbon monoxide, and non-methane organic compounds (NMOCs) such as trichloroethylene, benzene, and vinyl chloride.**
- **The following table lists "typical" landfill gases, their percent by volume, and their characteristics.**

5 - 5

Typical Landfill Gas Components

Component	Percent by Volume	Characteristics
methane	45–60	Methane is a naturally occurring gas. It is colorless and odorless. Landfills are the single largest source of U.S. man-made methane emissions.
carbon dioxide	40–60	Carbon dioxide is naturally found at small concentrations in the atmosphere (0.03%). It is colorless, odorless, and slightly acidic.
nitrogen	2–5	Nitrogen comprises approximately 79% of the atmosphere. It is odorless, tasteless, and colorless.
oxygen	0.1–1	Oxygen comprises approximately 21% of the atmosphere. It is odorless, tasteless, and colorless.
ammonia	0.1–1	Ammonia is a colorless gas with a pungent odor.
NMOCs (non-methane organic compounds)	0.01–0.6	NMOCs are organic compounds (i.e., compounds that contain carbon). (Methane is an organic compound but is not considered an NMOC.) NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, dichloromethane, carbonyl sulfide, ethyl-benzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.
sulfides	0–1	Sulfides (e.g., hydrogen sulfide, dimethyl sulfide, mercaptans) are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. Sulfides can cause unpleasant odors even at very low concentrations.
hydrogen	0–0.2	Hydrogen is an odorless, colorless gas.
carbon monoxide	0–0.2	Carbon monoxide is an odorless, colorless gas.

Source: Tchobanoglous, Theisen, and Vigil 1993; EPA 1995

5 - 6

How does landfill gas move?

Once gases are produced under the landfill surface, they generally move away from the landfill. Gases tend to expand and fill the available space, so that they move, or "migrate," through the limited pore spaces within the refuse and soils covering of the landfill.

The natural tendency of landfill gases that are lighter than air, such as methane, is to move upward, usually through the landfill surface.

Upward movement of landfill gas can be inhibited by densely compacted waste or landfill cover material (e.g., by daily soil cover and caps).

When upward movement is inhibited, the gas tends to migrate horizontally to other areas within the landfill or to areas outside the landfill, where it can resume its upward path. Basically, the gases follow the path of least resistance. Some gases, such as carbon dioxide, are denser than air and will collect in subsurface areas, such as utility corridors.

5 - 7

LFG Movement

Three main factors influence the migration of landfill gases: diffusion (concentration), pressure, and permeability.

- *Diffusion (concentration).* Diffusion describes a gas's natural tendency to reach a uniform concentration in a given space, whether it is a room or the earth's atmosphere.
  Gases in a landfill move from areas of high gas concentrations to areas with lower gas concentrations.
  Since, gas concentrations are generally higher in the landfill than in the surrounding areas, landfill gases diffuse out of the landfill to the surrounding areas with lower gas concentrations.

5 - 8

LFG Movement (cont.)

- ***Pressure.*** Gases accumulating in a landfill create areas of high pressure in which gas movement is restricted by compacted refuse or soil covers and areas of low pressure in which gas movement is unrestricted. (Ex 18 Leachate Geyser 11 2 23 (youtube.com))
- Pressure variation throughout the landfill results in gases moving from areas of high pressure to areas of low pressure. Movement of gases from areas of high pressure to areas of lower pressure is known as *convection*.
- As more gases are generated, the pressure in the landfill increases, usually causing subsurface pressures in the landfill to be higher than either the atmospheric pressure or indoor air pressure. When pressure in the landfill is higher, gases tend to move to ambient or indoor air.

5 - 9

LFG Movement (cont.)

- *Permeability.* Gases will also migrate according to where the pathways of least resistance occur.
- Permeability is a measure of how well gases and liquids flow through connected spaces or pores in refuse and soils.
- Dry, sandy soils are highly permeable (many connected pore spaces), while moist clay tends to be much less permeable (fewer connected pore spaces).
- Gases tend to move through areas of high permeability (e.g., areas of sand or gravel) rather than through areas of low permeability (e.g., areas of clay or silt).
- Landfill covers are often made of low-permeability soils, such as clay. Gases in a covered landfill, therefore, may be more likely to move horizontally than vertically.

5 - 10

LFG Constituents

- Major gases
  Methane (CH4)
  Carbon Dioxide (CO2)
- Trace gases - Hydrogen
- Moisture

5 - 11

Actual LFG Composition

- Methane (CH4) 45 to 58 %
- Carbon Dioxide (CO2) 35 to 45 %
- Oxygen (O2) >1 to 5 %
- Nitrogen (N2) >1 to 5 %
- Hydrogen (H2) >1 to 5 %
- Water Vapor (H20) >1 to 5 %
- Trace Organics >1 to 3 %

5 - 12

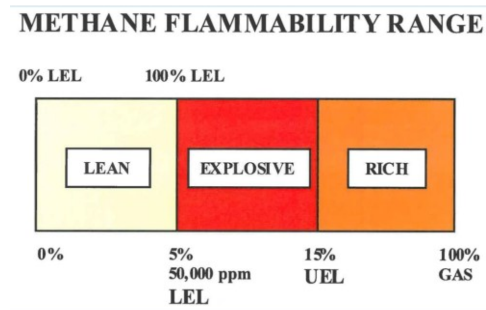
Primary LFG Characteristics

- LFG approx. 50% methane
- Methane is combustible/ explosive gas
- Lower explosive limit (LEL) = 5% CH4
  Lower – not explosive in air
- Upper explosive limit (UEL) = 15% CH4
  >15 %, too rich to be explosive in air
- Heat content of Gas from landfills
  Approx. 500 Btu/cu ft as compared to:
  Natural gas which is almost entirely CH4 and is approximately1,000 Btu/cu ft

Remember that 1% = 10,000 PPM

5 - 13

LFG Characteristics



5 - 14

UNCONTROLLED LANDFILL GAS CONSTITUENTS

Compound	VOC[a]	Hazardous Air Pollutant[b] (HAP)
1,1,1-Trichloroethane (methyl chloroform)	N	Y
1,1,2,2-Tetrachloroethane	Y	Y
1,1-Dichloroethane (ethylidene dichloride)	Y	Y
1,1-Dichloroethane (vinylidene chloride)	Y	Y
1,2-Dichloroethane (ethylene dichoride)	N	Y
1,2-Dichloropropane (propylene dichloride)	Y	Y
2-Propanol (isopropyl alcohol)	Y	N
Acetone	N	N
Acrylonitrile	Y	Y
Bromodichloromethane	Y	N
Butane	Y	Y
Carbon disulfide	Y	Y
Carbon monoxide[c]	N	N
Carbon tetrachloride	Y	Y
Carbonyl sulfide	Y	Y
Chlorobenzene	Y	Y
Chlorodifluoromethane	N	N
Chloroethane (ethyl chloride)	Y	Y
Chloroform	Y	Y
Chloromethane	Y	N

5 - 15

(CONTINUED)

Compound	VOC[a]	Hazardous Air Pollutant[b] (HAP)
Dichlorobenzene[d]	Y	Y
Dichlorodifluoromethane	N	N
Dichlorofluoromethane	N	N
Dichloromethane (methylene chloride)	N	Y
Dimethyl sulfide (methyl sulfide)	Y	N
Ethane	N	N
Ethanol	Y	N
Ethyl mercaptan (ethanethiol)	Y	N
Ethylbenzene	Y	Y
Ethylene dibromide	Y	Y
Fluorotrichloromethane	N	N
Hexane	Y	Y
Hydrogen sulfide	N	N
Mercury[e]	N	Y
Methyl ethyl ketone	Y	Y
Methyl isobutyl ketone	Y	Y
Methyl mercaptan	Y	N
Pentane	Y	N
Perchloroethylene (tetrachloroethylene)	N	Y
Propane	Y	N

5 - 16

(CONTINUED)

Compound	VOC[a]	Hazardous Air Pollutant[b] (HAP)
Trichloroethylene (trichloroethene)	Y	N
t-1,2-Dichloroethene	Y	N
Vinyl chloride	Y	Y
Xylenes	Y	Y

NOTE: This is not an all-inclusive list of potential LFG constituents, only those for which test data were available at multiple sites (EPA 1995).
[a] Reactive VOC.
[b] Hazardous Air Pollutants listed in Title III of the 1990 Clean Air Amendments.
[c] Carbon monoxide is not a typical constituent of LFG, but does exist in instances involving landfill (underground) combustion. Of 18 sites where CO was measured, only 2 showed detectable levels of CO.
[d] Source tests did not indicate whether this compound was the para-or ortho- isomer. The para- isomer is a Title III-listed HAP.
[e] No data were available to speciate total Hg into the elemental and organic forms.

5 - 17

Phases of Decomposition

- Aerobic Phase
- Anaerobic Facultative, acid forming and Early methanogenic
- Steady methanogenic Phase or accelerated methane production
- Mature, methane depletion or decelerated methane production phase
- All anaerobic decomposition is complete

5 - 18

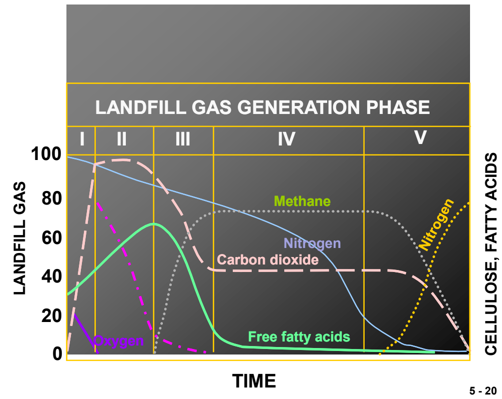
Phases of Decomposition

The first phase is aerobic (i.e., while O2 is available), and the primary gas produced is CO2. The second phase is characterized by O2 depletion, resulting in an anaerobic environment where large amounts of CO2 and some hydrogen (H2) are produced. In the anaerobic third phase, CH4 production begins, with an accompanying reduction in the amount of CO2 produced.

Nitrogen content is initially high in LFG in the aerobic first phase and declines sharply as the landfill proceeds through the anaerobic second and third phases. In the fourth phase, gas production of CH4, CO2, and N2 becomes fairly steady.

The phase, duration, and timing of gas generation vary with landfill conditions (i.e., waste composition, cover materials, moisture content, temperature, pH, etc.) and may also vary with climatic conditions such as precipitation rates and temperatures.

5 - 19



5 - 20

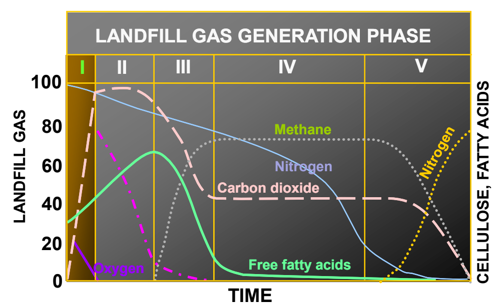
Phase I

During the first phase of decomposition, aerobic bacteria — bacteria that live only in the presence of oxygen—consume O2 while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste.

The primary byproduct of this process is carbon dioxide. Nitrogen content is high at the beginning of this phase but declines as the landfill moves through the four phases. Phase I continues until available O2 is depleted.

Phase I decomposition can last for days or months, depending on how much O2 is present when the waste is disposed of in the landfill.

5 - 21



5 - 22

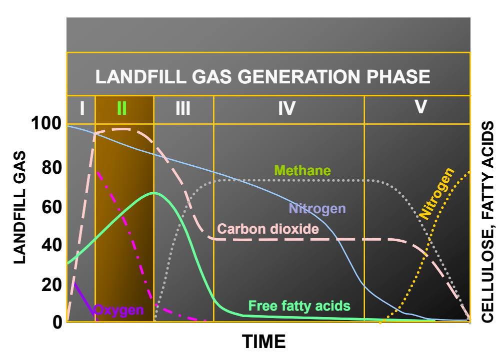
Phase II

Phase II decomposition starts after the O2 in the landfill has been used up. Using an anaerobic process (a process that does not require oxygen), bacteria convert compounds created by aerobic bacteria into acetic, lactic, and formic acids and alcohols such as methanol and ethanol.

The landfill becomes highly acidic. As the acids mix with the moisture present in the land-fill, they cause certain nutrients to dissolve, making nitrogen and phosphorus available to the increasingly diverse species of bacteria in the landfill.

The gaseous byproducts of these processes are carbon dioxide and hydrogen. If the landfill is disturbed or if O2 is some how introduced into the landfill, microbial processes will return to Phase I.

5 - 23



5 - 24

Phase III

Phase III decomposition starts when certain kinds of anaerobic bacteria consume the organic acids produced in Phase II and form acetate, an organic acid.

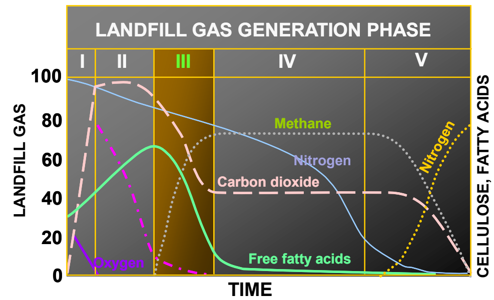
This process causes the landfill to become a more neutral environment in which methane-producing bacteria begin to establish themselves.

Methane- and acid-producing bacteria have a symbiotic, or mutually beneficial, relationship. Acid-producing bacteria create compounds for the methanogenic bacteria to consume.

Methanogenic bacteria consume the carbon dioxide and acetate, too much of which would be toxic to the acid-producing bacteria.

5 - 25

Phase III



5 - 26

Phase IV

Phase IV decomposition begins when both the composition and production rates of landfill gas remain relatively constant.

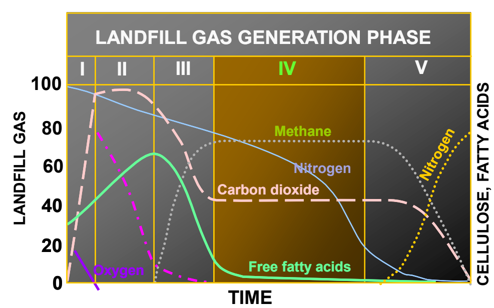
Phase IV landfill gas usually contains approximately 45 to 60 percent CH4 by volume, 40 to 60 percent CO2, and 2 to 9 percent other gases, such as sulfides.

Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill.

Gas production might last longer, for example, if greater amounts of organics are present in the waste, such as at a landfill receiving higher than average amounts of domestic animal waste.

5 - 27

Phase IV



5 - 28

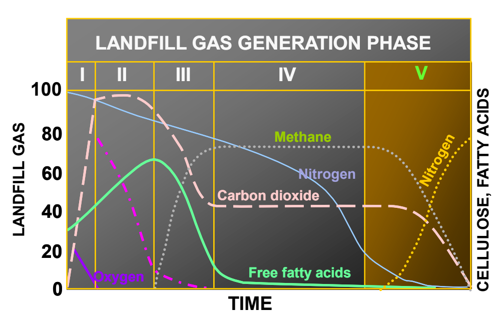
Phase V:

Transition to Stabilization

- Gas is primarily air
- All anaerobic decomposition is complete

5 - 29

Phase V



5 - 30

Factors Influencing Gas Generation

- Refuse quantity
- Refuse composition
- Refuse compaction
- Refuse age
- Moisture content !!!
- Liquid addition / bioreactors
- pH and alkalinity
- Nutrients
- Toxics
- Temperature

5 - 31

Modeling biological decomposition How much gas will a given volume of trash generate as it decomposes?

Methane Yield Potential (Lo)
1.4 to 7.0 cu ft / lb (LFG @50% methane) Average Landfill: 4.5 cu ft / lb (LFG @ 50% methane)
AP-42: 100 cm methane /Mg – 3.2 cu ft/ lb (LFG @50% methane)

5 - 32

How quickly will it be generated?

First Order Decay Rate Constant (k)
– How much gas a given volume of trash will generate per year
– Range: 0.07 to 0.27 cu ft / lb / yr
– Average: 0.15 cu ft / lb / yr

5 - 33

EPA United States Environmental Protection Agency

EPA-600/R-05/072
June 2005

First-Order Kinetic Gas Generation Model Parameters for Wet Landfills

5 - 34

Why Gas Generation Curves Are Needed

- Regulatory drivers
- Gas system design
- Gas system evaluations
- Beneficial use projects

5 - 35

Landfill's NMOC Emission Rate – 40 CFR part 60, Subpart XXX

- The process of calculating the landfill's NMOC emission rate is a four-step process. The steps are called 'Tier 1', 'Tier 2', 'Tier 3', and 'Tier 4'. The steps are in order of increasing precision and complexity.
- Tier 1 calculations are done using the landfill's year-to-year solid waste acceptance rate along with standardized factors for methane generation rate, NMOC concentration, methane generation potential, and NMOC concentration.
- Tier 2 calculations are done using the landfill's year-to-year solid waste acceptance rate, standardized rates for methane generation and methane generation potential, and a unique NMOC concentration determined by sampling landfill gas from your landfill.
- Tier 3 calculations are done using the landfill's year-to-year solid waste acceptance rate, the unique NMOC concentration determined by the Tier 2 sampling of landfill gas from the landfill, and a site-specific methane generation rate determined by drilling holes into the landfill and measuring the methane generation rate.
- Tier 4 is done using surface emissions monitoring and is allowed only if the landfill owner or operator can demonstrate that NMOC emissions are greater than or equal to 34 Mg/yr but less than 50 Mg/yr using Tier 1 or Tier 2.

5 - 36

Regulatory Requirements for Gas Generation Curves

- Tier I estimates (60.754(a)(2) (764.764(a)(2))
- Tier II estimates (60.754(a)(3) (764.764(a)(3))
- Tier III estimates (60.754(a)(4) (764.764(a)(4))
- Other methods (764.764(a)(5))
- Tier IV estimates (60.754(a)(6) (764.764(a)(4))

5 - 37

Test methods and Procedures - 60.754 60.764

(a)(1) The landfill owner or operator shall (must) calculate the NMOC emission rate using either the equation provided in paragraph (a)(1)(i) of this section or the equation provided in paragraph (a)(1)(ii) of this section. Both equations may be used if the actual year-to-year solid waste acceptance rate is known, as specified in paragraph (a)(1)(i), for part of the life of the landfill and the actual year-to-year solid waste acceptance rate is unknown.

5 - 38

Equation if waste acceptance rate is known

- **The following equation shall be used if the actual year-to-year solid waste acceptance rate is known.**

$$M_{NMOC} = \sum_{i=1}^{n} 2\,L_o\,M_i\,(e^{-kt_i})(C_{NMOC})(3.6 \times 10^{-9})$$

Where:

- MNMOC = Total NMOC emission rate from the landfill, megagrams per year.
- k = Methane generation rate constant, year−1. Lo = Methane generation potential, cubic meters per megagram solid waste.
- M_i = Mass of solid waste in the ith section, megagrams.
- t_i = Age of the ith section, years.
- C_{NMOC} = Concentration of NMOC, parts per million by volume as hexane.
- 3.6 × 10−9 = Conversion factor.

5 - 39

Equation if waste acceptance rate is unknown

(ii) The following equation shall be used if the actual year-to-year solid waste acceptance rate is unknown.

$$M_{NMOC} = 2Lo\,R\,(e^{-kc_i} - e^{-kt})\,C_{NMOC}\,(3.6 \times 10^{-9})$$

Where:

MNMOC = Mass emission rate of NMOC, megagrams per year.
Lo = Methane generation potential, cubic meters per megagram solid waste.
R = Average annual acceptance rate, megagrams per year
k = Methane generation rate constant, year−1.
t = Age of landfill, years.
CNMOC = Concentration of NMOC, parts per million by volume as hexane.
c = Time since closure, years; for active landfill c = 0 and e−kc = 1.

5 - 40

Tier I estimates [60.754(a)(2)] (764.764(a)(2))

If the NMOC emission rate calculated in paragraph (a)(1) of this section is less than 50 (34) megagrams per year, then the landfill owner shall submit an emission rate report as provided in § 60.757(b)(1) (60.767 (b)(1), and shall recalculate the NMOC mass emission rate annually as required under § 60.752(b)(1).

If the calculated NMOC emission rate is equal to or greater than 50 (34) megagrams per year, then the landfill owner shall either comply with § 60.752(b)(2), or determine a site-specific NMOC concentration and recalculate the NMOC emission rate using the procedures provided in paragraph (a)(3) of this section.

5 - 41

Subpart xxx

- §60.764(a)(2) Tier 1. The owner or operator must compare the calculated NMOC mass emission rate to the standard of 34 megagrams per year. (i) If the NMOC emission rate calculated in paragraph (a)(1) of this section is less than 34 megagrams per year, then the landfill owner or operator must submit an NMOC emission rate report according to §60.767(b), and must recalculate the NMOC mass emission rate annually as required under §60.762(b). (ii) If the calculated NMOC emission rate as calculated in paragraph (a)(1) of this section is equal to or greater than 34 megagrams per year, then the landfill owner must either:
- (A) Submit a gas collection and control system design plan within 1 year as specified in §60.767(c) and install and operate a gas collection and control system within 30 months according to §60.762(b)(2)(ii) and (iii);
- (B) Determine a site-specific NMOC concentration and recalculate the NMOC emission rate using the Tier 2 procedures provided in paragraph (a)(3) of this section; or
- (C) Determine a site-specific methane generation rate constant and recalculate the NMOC emission rate using the Tier 3 procedures provided in paragraph (a)(4) of this section.

5 - 42

Tier II estimates [60.754(a)(3)] 60.764(a)(3)

- The landfill owner or operator shall (must) determine the NMOC concentration using the following sampling procedure.
- The landfill owner or operator shall (must) install at least two sample probes per hectare of landfill surface that has retained waste for at least 2 years.
- If the landfill is larger than 25 hectares in area, only 50 samples are required. The sample probes should be located to avoid known areas of non-degradable solid waste.

5 - 43

Tier II estimates [60.754(a)(3)]

- If the landfill has an active or passive gas removal system in place, Method 25 or 25C samples may be collected from these systems instead of surface probes provided the removal system can be shown to provide sampling as representative as the two sampling probe per hectare requirement.
- For active collection systems, samples may be collected from the common header pipe before the gas moving or condensate removal equipment.
- For these systems, a minimum of three samples must be collected from the header pipe.

5 - 44

Tier II (cont.)

(ii) If the resulting mass emission rate calculated using the site-specific NMOC concentration is equal to or greater than 50 (34) megagrams per year, then the landfill owner or operator shall either comply with § 60.752(b)(2), or determine the site-specific methane generation rate constant and recalculate the NMOC emission rate using the site-specific methane generation rate using the procedure specified in paragraph (a)(4) of this section.

5 - 45

Tier II (cont.)

(iii) If the resulting NMOC mass emission rate is less than 50 (34) megagrams per year, the owner or operator shall submit a periodic estimate of the emission rate report as provided in § 60.757(b)(1) 60.767(b)(1) and (must) retest the site-specific NMOC concentration every 5 years using the methods specified in this section.

5 - 46

Tier III

- The site-specific methane generation rate constant shall be determined using the procedures provided in Method 2E of appendix A of this part.
- The landfill owner or operator shall estimate the NMOC mass emission rate using equations in paragraph (a)(1)(i) or (a)(1)(ii) of this section and using a site-specific methane generation rate constant k, and the site-specific NMOC concentration as determined in paragraph (a)(3) of this section instead of the default values provided in paragraph (a)(1) of this section.

5 - 47

Tier III (cont.)

(b) After the installation of a collection and control system in compliance with § 60.755, the owner or operator shall calculate the NMOC emission rate for purposes of determining when the system can be removed as provided in § 60.752(b)(2)(v), using the following equation:

$$M_{NMOC} = 1.89 \times 10^{-3} Q_{LFG}\, C_{NMOC}\, (3.6 \times 10^{-9})$$

(3.6×10^{-9}) =Conversion factor

5 - 48

Tier III (cont.)

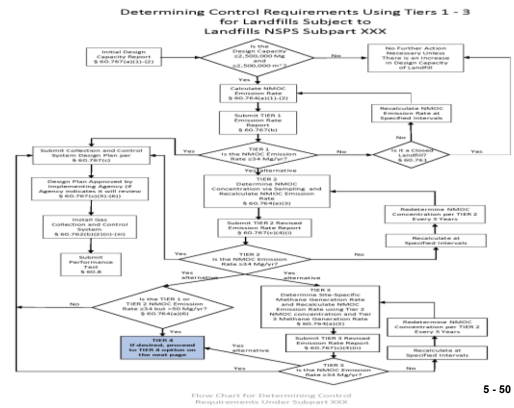
where, M_{NMOC} = mass emission rate of N_{MOC}, megagrams per year

Q_{LFG} = flow rate of landfill gas, cubic meters per minute

C_{NMOC} = NMOC concentration, parts per million by volume as hexane

(1) The flow rate of landfill gas, Q_{LFG}, shall be determined by measuring the total landfill gas flow rate at the common header pipe that leads to the control device using a gas flow measuring device calibrated according to the provisions of section 4 of Method 2E of appendix A of this part.

5 - 49

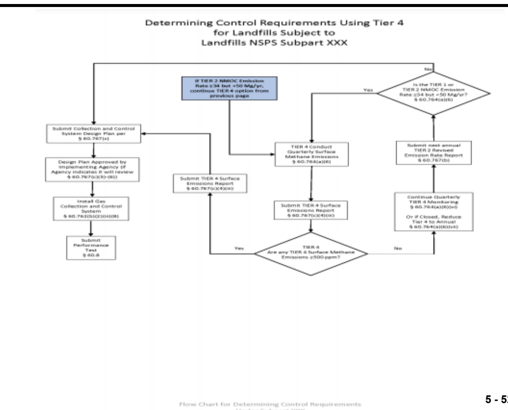


5 - 50

Tier 4

- The landfill owner or operator must demonstrate that surface methane emissions are below 500 parts per million. Surface emission monitoring must be conducted on a quarterly basis using the following procedures.
- Tier 4 is allowed only if the landfill owner or operator can demonstrate that NMOC emissions are greater than or equal to 34 Mg/yr, but less than 50 Mg/yr using Tier 1 or Tier 2.
- The owner or operator must measure surface concentrations of methane along the entire perimeter of the landfill and along a pattern that traverses the landfill at no more than 30-meter intervals using an organic vapor analyzer, flame ionization detector, or other portable monitor meeting the specifications provided in § 60.765(d).
- Surface emission monitoring must be performed in accordance with section 8.3.1 of Method 21 of appendix A of this part, except that the probe inlet must be placed no more than 5 centimeters above the landfill surface; the constant measurement of distance above the surface should be based on a mechanical device such as with a wheel on a pole, except as described in paragraph (a)(6)(iii)(A) of this section.

5 - 51



5 - 52

Regulations Share similar Regulations Language

- EG Subpart OOO and NESHAP AAAA also have Tier 1 through 4 and a Other Methods section, very similar to XXX.

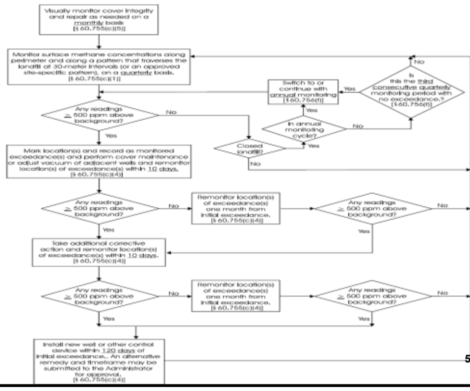
[EPA Regulation Navigation Tools | US EPA]

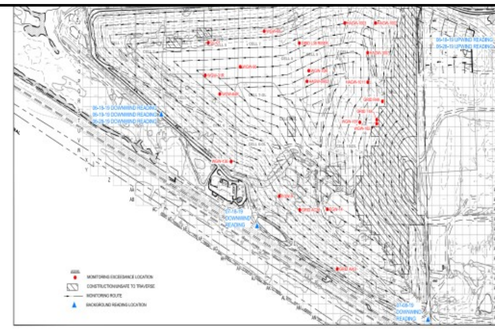
5 - 53

Surface Scans

5 - 54

Flow Chart of Surface Monitoring Requirements (WWW)





The following areas exhibited FID readings greater than 200 ppm above background during the second quarter of 2019:

Date	Grid	Location	Description	Reading (ppm)
6/18/19	P47	HAGW1011	Ground Penetration	376
6/18/19	AI43	Grid AI43	Soil Area	289
6/18/19	T46	West GW-181	Ground Penetration	370
6/18/19	P39	HAGW0902	Ground Penetration	230
6/18/19	J48	HAGW1002	Ground Penetration	1,372
6/18/19	M47	HAGW1007	Ground Penetration	2,156
6/18/19	R49	Grid R49 Well	Ground Penetration	> 10,000
6/18/19	T48	West GW-182	Ground Penetration	3,167
6/18/19	T48	Grid T48 Well	Ground Penetration	1,310
6/18/19	AB35	East GW-9	Ground Penetration	1,158
6/18/19	AC38	Grid AC38	Distressed Vegetation	791

Date	Grid	Location	Description	Reading (ppm)
6/18/19	O39	West GW-70R	Ground Penetration	1,431
6/18/19	L38	Riser	Ground Penetration	3,510
6/18/19	J44	HAGW1003	Ground Penetration	3,410
6/19/19	AC42	East GW-14	Ground Penetration	436
6/19/19	Q28	West GW-64R	Ground Penetration	567
6/19/19	O26	West GW-31R	Ground Penetration	1,013
6/19/19	K33	West GW-68	Ground Penetration	674
6/19/19	L26	SC-01	Ground Penetration	4,261
6/19/19	N30	West GW-90	Ground Penetration	1,611
6/19/19	X29	West GW-136	Ground Penetration	5,436

HAGW1011 Location Photos

1. HAGW1011
   - 6/18/2019
   - Initial Reading – 376 ppm

HAGW1011
- Corrective Action: Repaired liner around well
- 6/28/2019
- 10-Day Follow Up Reading – 620 ppm

- Corrective Action: Additional repairs made to liner around well
- 7/8/2019
- Additional 10-Day Follow Up Reading – 22.3 ppm

Grid A143 Location Photos

2. Grid AI43
   - 6/18/2019
   - Initial Reading – 289 ppm

Grid AI43
- Corrective Action: Added cover soil to area
- 6/28/2019
- 10-Day Follow Up Reading – 7.1 ppm

Elevated Temperature Landfills (ETLF's)

- Symptoms of ET conditions:
- Increased temperature of the gas at individual wellheads or in header
- Gas composition changes may also be symptomatic of the onset of ET conditions.
- Increased liquid in the landfill
- Changes in the chemical composition of the leachate or liquid extracted from the gas wells.
- Large and rapid sinkholes at the waste surface
- Inhibit methanogens microbes thereby reducing methane content in the gas
- Increase hydrogen content in the gas since

Potential Problems from ETLF's

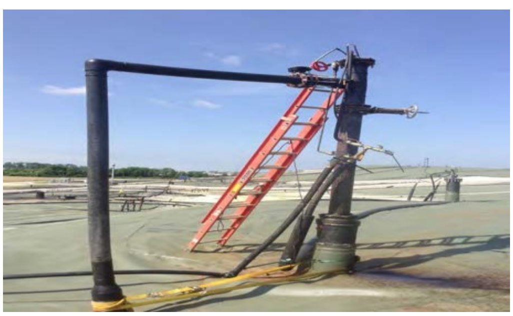
- Damage to gas and leachate collection systems
- Low methane content and odorous gas
- High leachate strength (COD upwards of 50,000 mg/L)
- Rapid settlement
- Pressure accumulation

5 - 61

Elevated Temperature Landfills (ETLF's) Mitigation

- Contain & Manage
- Enhanced cover – soil, EGC
- Enhanced GCCS
- Liquids management
- Leachate management/treatment
- Stabilize to mitigate effects of volume reduction
- Fugitive emission/odor control
- Long-term enhanced O & M

Differential Settling requiring well Modification



5 - 63

Siloxanes

- **Siloxanes** are volatile organic silicon compounds (VOSCs), which are present at the parts-per-million volumetric (ppmv) level in **landfill gas** (LFG) and digester gas.
- Siloxanes are found in personal health and beauty products and in commercial applications
- When VOSCs burn, they primarily form carbon dioxide (CO_2), water, and silicon dioxide. Silicon dioxide is commonly known as silica.

5 - 65

Siloxanes In LFG Issues

- Siloxanes are common contaminants in landfill gas (LFG).
- Siloxanes present in LFG can degrade the operating efficiency of LFGTE engines.
- Elevated siloxane concentrations can also potentially result in LFGTE facilities exceeding permitted emission limits for particulate matter (PM) and carbon monoxide (CO)
- Siloxanes may prevent landfills from demonstrating compliance with health-based guidelines for formaldehyde emissions.
- High siloxane concentrations can increase operating costs
- Siloxanes can foul post-combustion such as catalytic emissions controls.

5 - 66

Organosilicon Compounds Commonly Detected in LFG

CAS No.	Compound name and Abbreviation	Formula
1066-40-6	Trimethylsilanol (TMS)	$Si-OH-(CH_3)_3$
107-46-0	Hexamethyldisiloxane (L2)	$Si_2-O-(CH_3)_6$
541-05-9	Hexamethylcyclotrisiloxane (D3)	$Si_3-O_3-(CH_3)_6$
107-51-7	Octamethyltrisiloxane (L3)	$Si_3-O_2-(CH_3)_6$
556-67-2	Octamethylcyclotetrasiloxane (D4)	$Si_4-O_4-(CH_3)_8$
141-62-8	Decamethyltetrasiloxane (L4)	$Si_4-O_3-(CH_3)_{10}$
541-02-6	Decamethylcyclopentasiloxane (D5)	$Si_5-O_5-(CH_3)_{10}$
141-63-9	Dodecamethylpentasiloxane (L5)	
540-97-6	Dodecamethylcyclohexasiloxane (D6)	

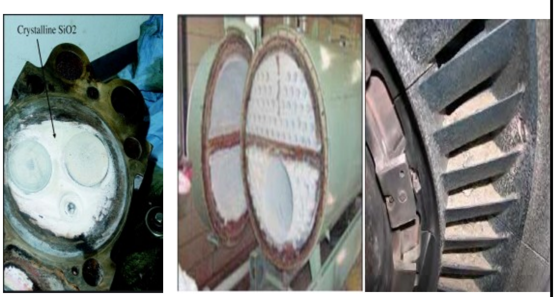
5 - 67

Properties of Selected VOSC's

Compound	MW	% Silicon	Vapor Pressure mmHg	Boiling Point (°F)	Water Solubility (mg/l)
D_3	222	38.0%	10	273	1.560
D_4	297	37.8%	1.3	347	0.056
D_5	371	37.9%	0.4	410	0.017
L_2	162	33.4%	42	214	0.930
L_3	236	35.7%	3.9	306	0.034

5 - 68

Siloxane Buildup on Combustion Equipment



5 - 69

How everyday products are supercharging landfill gas, and what that means

https://news.umich.edu/

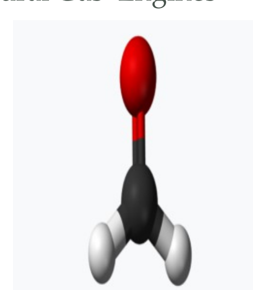
5 - 70

VOSC Limits for LFG Utilization

Technology	Limit mg Si/m³
Reciprocating Engines	5 to 20
Vehicle Fuel	12
Combustion Turbines (without Recuperation)	5
Combustion Turbines (with Recuperation)	2.5
Microturbines	0.3
Pipeline Quality Gas	0.1 to 0.4

5 - 71

Formaldehyde Emissions From Landfill Gas & Natural Gas Engines



5 - 72

Landfill Gas Engine Stack Test Formaldehyde Emissions Rates

Fuel	Engine Type	Max Permitted Heat Input (MMbtu/hr)	HCHO (lb/MMbtu)	HCHO (lb/MMscf)	VOC (adjusted for HCHO) lb/MMbtu	Percent HCHO
LFG	4-Stroke Lean Burn	16.54	.061	34.16	.094	65%
LFG	4-Stroke Lean Burn	16.54	.027	15.12	.054	50%
LFG	4-Stroke Lean Burn	16.54	.002	1.12	.033	6%
LFG	4-Stroke Lean Burn	16.1	.071	39.76	.158	45%
LFG	4-Stroke Lean Burn	16.1	.072	40.32	.128	56%
LFG	4-Stroke Lean Burn	16.1	.076	42.56	.077	99%
LFG	4-Stroke Lean Burn	16.1	.066	36.96	.067	99%
LFG	4-Stroke Lean Burn	16.1	.064	35.80	.121	53%
LFG	4-Stroke Lean Burn	16.1	.065	36.40	.066	98%
LFG	4-Stroke Lean Burn	16.63	.099	55.44	.134	74%
LFG	4-Stroke Lean Burn	16.63	.113	63.28	.172	66%
LFG	4-Stroke Lean Burn	16.63	.103	57.68	.140	74%

9/6/2018 |Division of Air Quality | NJDEP |

5 - 73

Natural Gas Engine Stack Test Formaldehyde Emissions Rates

Fuel	Engine Type	Max Permitted Heat Input (MMbtu/hr)	HCHO (lb/MMbtu)	HCHO (lb/MMscf)	VOC (adjusted for HCHO) lb/MMbtu	Percent HCHO
NG	2-Stroke Lean Burn	20.3	0.104	106.08	1.651	6%
NG	2-StrokeLean Burn	20.3	0.100	102.00	0.395	25%
NG	2-Stroke Lean Burn	20.3	0.081	82.62	0.588	14%
NG	4-Stroke Lean Burn	18	0.033	33.66	0.095	35%
NG	4-Stroke Lean Burn	18	0.032	32.64	0.032	100%
NG	4-Stroke Lean Burn	18	0.025	25.50	0.241	10%
NG	4-Stroke Lean Burn	18	0.036	36.72	0.176	20%
NG	4-Stroke Lean Burn	18	0.039	39.78	0.039	100%
NG	4-Stroke Lean Burn	18	0.041	41.82	0.041	100%
NG	4-Stroke Lean Burn	18	0.042	42.84	0.042	100%
NG	4-Stroke Lean Burn	18	0.038	38.76	0.038	100%

5 - 74

OTHER FORMALDEHYDE EMISSIONS FACTORS FOR LFG

- 0.1350 lb / MMscf [1] ≈ .000241 lb / Mmbtu [2]

EPA VOC Speciation Profile #1001 1/90 (1990) for LFG enclosed flares & Engines

- 0.22 g/bhp -hr[3] ≈ .069 lb / Mmbtu [4]

NACAA/PWIA (2017)

1.San Diego County (1999) < https://www.sandiego county .gov/content/dam /sdc/apcd/PDF/Misc/EFT/Gas_Combustion/APCD_Engine_Landfill_Gas_Fired.pdf
- FLARE Factor (lower) 2017
<http://pubs.awma.org/flip/EM -Mar-2017/damiano.pdf>

2.Assumes 560 btu /scf heating value of landfill gas
3.A&WMA. *What's the Best Way to Manage Landfill Gas: From an Environmental Perspective*
4.Employs AP-42 Table 3.3- 1 brake specific fuel consumption of 7000 btu / hp-hr>

5 - 75

Stack Testing Methods

- **NMHC/NMNEHC**
- – EPA Methods 25A and 18, or one or more of the Alternative Methods for these sources (ALT - 066, ALT-078, ALT-096, ALT-097 and /or ALT - 106).
- **Formaldehyde** – EPA Method 323 or Method 320. Note that EPA Method 316 is **not acceptable** , as it is specific to the Mineral Wool and Wool Fiberglass Industries.
- VOC (lb /hr) = NMHC/NMNEHC + HCHO

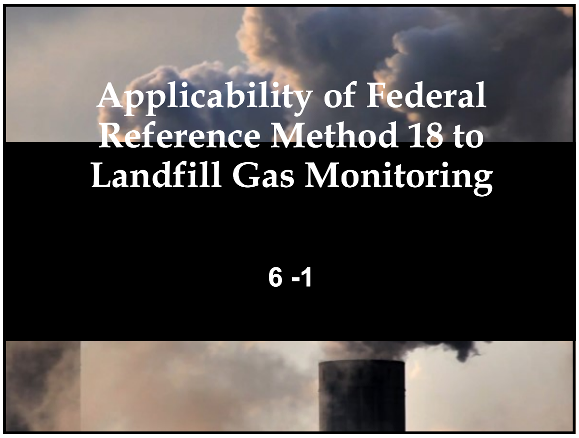
5 - 76

Emerging Landfill Contaminants by Stephen Zemba, Russell Abell, and Harrison Roakes

Landfill operations have long been regulated for contaminants such as heavy metals and toxic organic compounds. However, environmental professionals must now become aware of certain additional contaminants of emerging concern that are associated with landfills and are receiving new scrutiny for posing potential environmental risks.

5 - 77

em • The Magazine for Environmental Managers • A&WMA • March 2019



6 -2

40CFR60

- Part 60.764, Test Methods and Procedures, specifies the use of Federal Reference Method 18 during the Tier 2 and Tier 3 evaluation

6 -3

Evaluation of Landfill Gas Emissions

- Tier 1: Calculate NMOC Emission Rate using default values
- Tier 2: Determine NMOC Emission Rate Using FRM 18 and 25C
- Tier 3: Determine Methane Generation Rate Using FRM 2E
- Tier 4: Surface Emissions Monitoring using Method 21 and possibly 2E, 25 or 25E.

6 -4

Applicability

- Provides concentration data on approximately 90% of total volatile gaseous organic mass emitted from an MSW
- FRM 18 provides speciated data of volatile gaseous organic compounds which compose the NMOC concentration

6 -5

Applicability

- Method 18 will not determine compounds that
  - Are polymeric (high molecular weight)
  - Can polymerize before analysis
  - Have very low vapor pressure in ambient air or LFG

6 -6

Principle

- Sample is extracted from the MSW landfill stream and captured by various techniques
- The trapped sample is returned to the laboratory where the various volatile gaseous organics are separated in a gas chromatographic column and measured separately by a suitable detector

6 -7

Method Criteria

- Range: 1 ppm to upper limit of GC detector (Saturation of detector limiting factor. Upper limit can be extended by dilution)
- Sensitivity: Minimum detection limit or signal-to-noise ratio 3:1

6 -8

Method Criteria

- Precision: 5% to 10% RSD of mean value (Usually 5% with experienced GC operator)
- Accuracy: 10% audit sample value

6 -9

Interferences

- Resolution interferences (May be eliminated by GC column selection and column physics)
- Contamination of analytical system (Checked by periodic analyses of blanks)

6 -10

Interferences

- Cross-contamination from analysis of high to low concentration (Prevented by purging system between analyses)
- Water vapor (Correction factor developed)

6 -11

FRM 18 Overview

- Generic GC method
- For speciated VOCs
- Any combination of
  - Sampling technique, GC column, detector
  - User decides combo as long as recovery criteria are met (70-130%)
  - Recovery performed once per source

6 -12

Method 18 Pre-survey

- A pre-survey shall be performed on each MSW landfill to be tested to obtain all information necessary to design emission test
- Pre-survey optional if target compounds are known

6 -13

Method 18 Pre-survey

- Only place where canisters are allowed
- Grab sample, qualitative analysis, GC/MS for identification

6 -14

Pre-survey Data Needed

- Vent temperature and temperature range
- Approximate particulate concentration
- Static pressure
- Water vapor content

6 -15

Pre-survey Sample Train

- 250 mL double-ended glass sampling flask (Specified cleaning procedures provided)
- Evacuated flask
- Tedlar® or aluminized Mylar® flexible bag
- Adsorption tubes

6 -16

Pre-survey Sample Analysis

- Select GC columns based upon manufacturer's recommendation
- Select GC conditions for good resolution by varying conditions after 1st injection

6 -17

Pre-survey Sample Analysis

- Heat pre-survey sample to vent temperature
- Analyze pre-survey samples using retention time (RT) compared to calibration standards

6 -18

Criteria for Pre-survey and Sample Analysis

- Prepare calibration standards by proper technique
- Determine optimum GC settings
- Obtain retention times with repeatability of +/- 0.5 seconds

6 -19

Criteria for Pre-survey and Sample Analysis

- Use sampler sample loop or dilution if necessary
- Identify all peaks >5% of the total area

6 -20

FRM 18 Basic Sampling Systems

- Whole air sampling (Active/Passive)
  - Tedlar® Bag
  - Glass Sampling Bulb
- Adsorbent tubes (Active/Passive)
  - Charcoal/Silica Gel/Florisil
  - CarboTrap 300/Tenax®TA

6 -21

FRM 18 Basic Sampling Systems

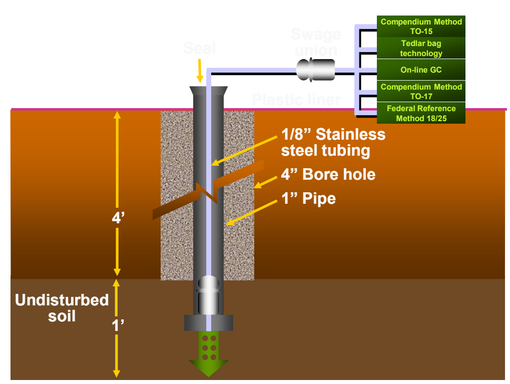
- Headspace Sampling
- Direct Interface

6 -22

FRM 18 Direct Interface Sampling Method

- Direct Interface:
  Sample continuously pumped from landfill gas sampling probe to GC by heated line. Analysis conducted on discrete gas samples from sample loop. All compounds must be separated by one column/detector combination

6 -23



6 -24

Direct Interface Sampling Setup

- Apparatus: Sample probe, sample line, sample pump, sample valve, flow meters and heated box
- Assemble equipment and leak-check
- Heat sample probe, line, and sample box to 1-3°C above landfill gas temperature

6 -25

Direct Interface Sampling Setup

- Analyze calibration gas in the sample line immediately following the probe

6 -26

Direct Interface Sampling

- Calibration gas analysis should be accurate within 10%
- Reconnect probe, analyze landfill gas
- Reanalyze landfill gas (two analyses must agree within 5%)

6 -27

FRM 18 Direct Interface/Dilution Sampling

- Same apparatus as direct interface except a dilution system is added between heated sample line and the gas sampling valve
- Apparatus arranged so either a 10:1 or 100:1 dilution of source gas can be directed to the GC analyzer

6 -28

FRM 18 Direct Interface/Dilution Sampling

- Verify accuracy of dilution system by analyzing calibration gas with agreement of within 10%

6 -29

Sampling: Direct Interface

- Strengths
  - Sample collected retains compounds/immediate analysis
  - No loss or alteration to compounds
  - Method of choice for steady state processes when duct temperature is below 100°C and organics suitable for GC analysis

6 -30

Sampling: Direct Interface

- Weaknesses
  - GC at site, can't integrate sample, non-steady state poor

6 -31

Glass Sampling Flask

- Samples can be collected in pre-cleaned 250 mL double-ended sampling flask
  - Cleaning of flask: methylene chloride, soap solution, furnace
- Sampling performed by either
  - Evacuated flask procedure
  - Purged flask procedure

6 -32

FRM 18 Glass Sampling Flask Procedure

- Use clean flask
- Attach "T-connection" to inlet of flask
- Attach 6-mm OD borosilicate sampling probe with 12-mm OD enlargement at end containing glass wool plug for particle control

6 -33

FRM 18 Glass Sampling Flask Procedure

- Use rubber suction bulb to purge probe
- Attach end of flask to a rubber suction bulb
- Attach probe used in evacuated flask procedure to inlet of flask

6 -34

FRM 18 Glass Sampling Flask Procedure

- Purge flask, then close stopcock near suction bulb
- Then close stopcock near probe
- Tape stopcocks to prevent leakage

6 -35

FRM 18 Flexible Bag Sampling

- Samples collected in Tedlar® or aluminized Mylar® flexible bags
- Flexible bag certification
  - Use new bag
  - Leak check
  - Check for contamination with nitrogen/24-hours, then analyze by GC

6 -36

FRM 18 Flexible Bag Sampling Procedure

- Assemble sampling train
- Leak check both the bag and container
- Purge probe line
- Evacuate container containing flexible bag

6 -37

FRM 18 Flexible Bag Sampling Procedure

- Sample three bags (Proportional single point sampling)
- Analyze bag in triplicate
- Spike one of the bags
- Store for hold time period
- Analyze bag in triplicate

6 -38

FRM 18 Flexible Bag Sampling Procedure

- Recovery must be 70-130%
- Must analyze performance evaluation (PE) sample prior to analysis of landfill gas
- Audit analysis must agree with the audit concentrations within 10%

6 -39

Bag Sampling and Condensation

- Heat sampling box containing sample bag to vent temperature
- Maintain temperature of bag until analysis
- Add dropout impinger to collect condensate (Must be analyzed for VOCs along with bag analysis)

6 -40

Sampling: Tedlar® Bag

- Strengths
  - Sample collected over time and has same compounds and concentrations as stack emissions
  - Sample may be returned to laboratory for analysis
  - Multiple analysis

6 -41

Sampling: Tedlar® Bag

- Weaknesses
  - Tedlar® bags awkward and bulky for shipment, stability of compounds, can't do polar

6 -42

FRM 18 Adsorbent Tube Procedure

- Samples collected (active/passive) in absorbent tube containing specific amounts of adsorbent per primary/backup sections
  - 800/200 mg for charcoal tubes
  - 1040/260 mg for silica gel tubes

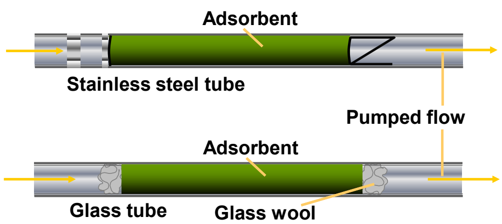
6 -43

FRM 18 Adsorbent Tube Procedure

- Alternative, adsorbents such as Tenax® GC or XAD-2® can be used
- Typical tube design: 90 mm x 6 mm

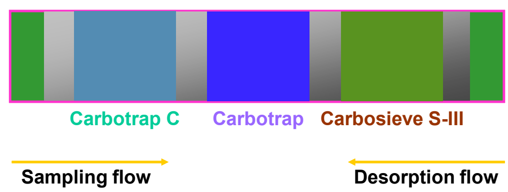
6 -44

Single Tube Design- Glass/Stainless Steel



6 -45

Multi-bed Adsorbent Trap



6 -46

6 -47

Adsorbent Tube Apparatus

- Heated probe (~ 6 mm ID)
- Filter (heated)
- Flexible tubing
- Leakless sample pump

6 -48

Adsorbent Tube Apparatus

- Rotameter
- Adsorption tube
- All temperature and flow measuring devices must be calibrated

6 -49

Adsorbent Tube Sampling

- Determine "sample loading factors" in order to design sampling approach
- Perform recovery study of the compounds of interest during the actual field test
  - Two identical sampling trains co-located in sampling vent

6 -50

Adsorbent Tube Sampling

  - One train spiked (all compounds of interest) and the other unspiked train
  - Mass spiked should be 40-60% of mass expected to be collected by unspiked train
- Sample the exhaust of the landfill gas with the co-located sampling trains for a total of 3 runs

6 -51

Adsorbent Tube Sampling

- Determine the fraction of spiked compound recovered
- Criteria of 70<R<130% must be met in order for sampling technique to be used for specific analyte

6 -52

Adsorbent Tube Sampling Requirements

- Any commercially available adsorbent is allowed
- May use water knockout impinger before adsorbent
- Must perform dual sampling trains: one spiked and one unspiked

6 -53

Adsorbent Tube Sampling Requirements

- Three dual-sampling trains constitute a test
- Desorption/analysis usually in lab
- May do solvent or thermal desorption for recovery of VOCs

6 -54

Adsorbent Tube Sampling Requirements

- If solvent desorption, analyze each in triplicate
- If thermal desorption, analyze each sample once
- Recovery must be 70-130%

6 -55

Sampling: Adsorbent Tubes

- Strengths
  - Sample compact and easy to use
  - Sample returned to laboratory for analysis
  - Good sample storage time

6 -56

Sampling: Adsorbent Tubes

- Weaknesses
  - Quantitative recovery poor
  - Breakthrough possible
  - Moisture Effects

6 -57

Which Sampling Technique Should Be Used?

- Direct Interface: Excellent, real-time if all analytes can be separated by one column/detector combination
- Dilution Interface: Same as direct interface; Excellent if high concentrations of target compounds are present

6 -58

Which Sampling Technique Should Be Used?

- Adsorbent Tube: Excellent if concentrations of target compounds are sub-ppm levels
- Bag Sampling: Everybody's favorite; Cheap; Excellent when more than one detector is needed; Excellent for explosive environments

6 -59

Headspace Sampling

- This method examines contaminants that are present in a headspace above a contained soil sample or an atmosphere within a confined area for analysis

6 -60

Emission Flux Sampling (Headspace Sampling)

- Sampling the headspace gas within the confined chamber usually involves active sampling or real-time monitoring utilizing solid adsorbent tubes, whole air sampling devices or real-time VOC GC systems

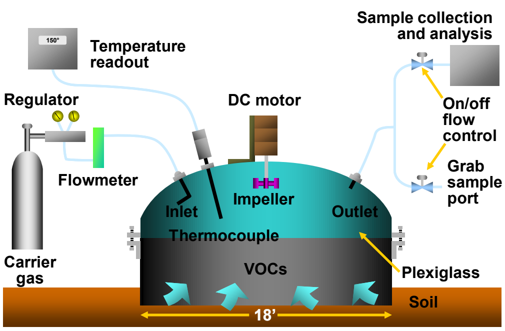
6 -61

Emission Flux Sampling (Headspace Sampling)

- Emission Flux Sampling involves placing a container above the surface areas of the landfill and allowing emissions to permeate through the soil and be confined within the chamber area

6 -62

Emission Flux Chamber



6 -63

Passive Adsorbent Sampling as Headspace Sampling

- Passive adsorbent sampling as headspace involves sampling the atmosphere with a solid adsorbent in the passive mode. Gas enters the adsorbent according to Fick's Law of Diffusion.

6 -64

Method 18 Applicability to Landfill Gas Monitoring

- Method applicable to most sampling programs:
  - Good with 10 or less compounds
  - Compounds are known
  - Fairly high vapor pressure at room temperature
    - ppb to ppm levels dependent on use of adsorbent or Tedlar® bag

6 -65

Method 18 Applicability to Landfill Gas Monitoring

- Mass balance around system is required
- Should not be used after combustion source unless compounds identifiable

6 -66

Preparation of Calibration Standards

- Liquid standard in desorbing solution
- Direct analysis of NIST reference gases or commercial certified gas mixtures

6 -67

Preparation of Calibration Standards

- Gas dilution from high concentration of gas cylinder using calibrated rotameters

6 -68

Preparation of Calibration Standards

- Direct syringe-bag dilution for known quantity volatile liquid material
- Indirect syringe-bag dilution for known quantity of less volatile liquid materials

6 -69

Final Sampling and Analysis Procedure

- Consider safety and source conditions, select appropriate sampling and analysis procedures (Use direct interface if source < 100°C and organics suitable for detection)

6 -70

Final Sampling and Analysis Procedure

- If source has high concentration (> 100 ppm), then select direct dilution interface technique

6 -71

Compliance Test: Direct/Dilution Interface

- On-line, on-site GC
- Real-time analysis
- Triplicate injections, 3 concentrations of each target compound
- Calibration gas must be certified to 2% accuracy by manufacturer

6 -72

Compliance Test: Direct/Dilution Interface

- **Method 25 allowed**
- **Recovery study basically leak-check, 70-130% recovery**
- **Five consecutive samples equals a run**

6 -73

Compliance Test: Direct/Dilution Interface

- **Post-test calibration check: If > 5% difference, use both curves. If <5% difference, use first curve generated**

6 -74

Method 18 Summary

- **Source has great flexibility in choosing sampling/analytical methodology (As long as recovery criteria are met)**
- **Encourage direct/dilution interface: Real-time data, less chance of sampling loss**
- **Any detector, including mass spectrometer, may be used**

6 -75

Method 18 Summary

- **Any adsorbent is allowed as long as recovery met**
- **Recovery procedures done once per source**
- **Canisters are not allowed except for pre-survey**

6 -76

Method 18 Regulation References

- **63.1960 Compliance provisions.**
- (a) Except as provided in § 63.1981(d)(2), the specified methods in paragraphs (a)(1) through (6) of this section must be used to determine whether the gas collection system is in compliance with § 63.1959(b)(2)(ii)

$$Qm = 2L_0R\,(e^{-kc} - e^{-kt})\ \text{(Eq. 5)}$$

Method 18 Regulation References

Where:

Qm = Maximum expected gas generation flow rate, m3/yr.

Lo = Methane generation potential, m3/Mg solid waste.

R = Average annual acceptance rate, Mg/yr.

k = Methane generation rate constant, year $^{-1}$

t = Age of the landfill at equipment installation plus the time the owner or operator intends to use the gas mover equipment or active life of the landfill provided by § 63.1981(d)(2). EPA Method 3, 3A, or 3C of appendix A–7 to part 60 must be used to determine oxygen for correcting the NMOC concentration as hexane to 3 percent. In cases where the outlet concentration is less than 50 ppm NMOC as carbon (8ppm NMOC as hexane), EPA Method 25A should be used in place of EPA Method 25. EPA Method 18 may be used in conjunction with EPA Method 25A on a limited basis (compound specific, *e.g.*, methane) or EPA Method 3C may be used to determine methane. The methane as carbon should be subtracted from the EPA Method 25A total hydrocarbon value as carbon to give NMOC concentration as carbon. The landowner or operator must divide the NMOC concentration as carbon by 6 to convert from the CNMOC as carbon to CNMOC as hexane. Equation 4 must be used to calculate efficiency:

$$\text{Control Efficiency} = (NMOC_{in} - NMOC_{out})/(NMOC_{in}) \qquad \text{(Eq. 4)}$$

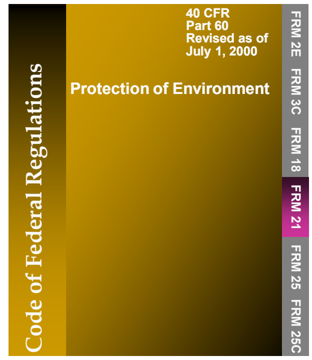
63.1961 Monitoring of operations.

- Monitor the methane concentration with a methane meter using EPA Method 3C of appendix A– 6 to part 60, EPA Method 18 of appendix A–6 to part 60 of this chapter, or a portable gas composition analyzer to monitor the methane levels provided that the analyzer is calibrated and the analyzer meets all quality assurance and quality control requirements for EPA Method 3C or EPA Method 18.

Federal Reference Method 21

Determination of Volatile Organic Compounds Leaks

7- 1



7 - 2

7 - 3

Lesson Objectives

- Review Federal Reference Method 21 (FRM 21)
- Examine instrument and performance criteria
- Identify typical equipment which meets FRM 21 specifications

7 - 4

Applicability

- FRM 21 applies to the determination of volatile organic compounds (VOCs).
- Under New Source Performance Standards (NSPS), Subpart WWW, (XXX) 60.755(a)(6)(c)(3), FRM 21 is identified as the instrumentation, specification, and procedures for surface emission monitoring

7 - 5

FRM 21

- FRM 21 describes a procedure to be followed in using a hand-held instrument to measure for methane/VOC leaks at an MSW landfill

7 - 6

Portable VOC Analyzers

- Portable VOC analyzers fall within two classes:
  - Single Hand-held Unit
  - Multi-component Hand-held Unit

7 - 7

FRM 21 Multi-component Hand-held Unit

- Probe/Interface
  - Probe/probe extension not to exceed ¼" OD
  - Optional meter/readout capability
  - Optional particulate filter
- Umbilical Cord

7 - 8

FRM 21 Multi-component Hand-held Unit

- Analytical Assembly
  - Pump/flow controller
  - Analytical Instrument (Detector, Cal Gas, Regulator, Power)
  - Data acquisition system

7 - 9

FRM 21 Requirements

- Instrument specifications
- Performance specifications

7 - 10

Six Instrument Specifications

- 1. VOC Response - The instrument must respond to the compound of interest. For Subpart WWW, the compound of interest is methane (CH_4)

7 - 11

Six Instrument Specifications

- 2. Measurement Range - Must encompass the defined monitoring exceedance of greater than 500 ppm, background corrected
- 3. Scale Resolution - The instrumentation must have a scale resolution of 12.5 ppm methane

7 - 12

Six Instrument Specifications

- 4. Nominal sample flow rate specification - As measured at the probe tip, shall be 0.10 to 3.0 liters per minute

7 - 13

Six Instrument Specifications

- 5. Intrinsically Safe - The instrument must be intrinsically safe in at least Class I, Division I area.

7 - 14

Six Instrument Specifications

- 6. Sampling Probe No Greater Than ¼ Inch - The instrument must have a sample probe with an outer diameter (OD) of ¼ inch

7 - 15

FRM 21 Performance Criteria

- Response factor determination
- Calibration precision test
- Response time test

7 - 16

FRM 21 Allows Various Detectors

- Flame ionization
- Photoionization
- Catalytic oxidation
- Infrared adsorption

7 - 17

Flame Ionization Detector (FID) Characteristics

- Sample gas drawn in continuously
- Sample gas mixed with hydrogen and methane (VOCs) burn in flame to form positive charged ions
- Positive ions are generated during combustion and migrate to the collection plate

7 - 18

Flame Ionization Detector (FID) Characteristics

- Amplification circuit counts ions which are directly proportional to concentration

7 - 19

Photoionization Detector (PID) Characteristics

- Sample gas drawn in continuously
- Sample gas ionized by absorption of light
- Positive ions formed and collected
- Current produced is amplified and measured

7 - 20

Response Factor Performance Criteria

- Response factor determination must be performed before putting the instrument into service
- FRM 21 allows the use of manufacturer's response factors
- For methane, the response factor is 1

7 - 21

Response Factor Performance Criteria

- The instrument response factor for target analyte must be < 10

7 - 22

Response Factor

- Response Factor (RF)

$$RF = \frac{\text{Actual Concentration}}{\text{Instrument Observed Concentration}}$$

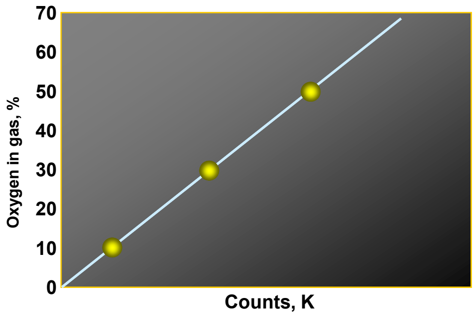
- Typical RF:
  - Benzene: 0.29 (Very Sensitive)
  - Chloroform: 9.28 (Not So Sensitive)

7 - 23

Response Factor Table

Challenge Concentration (ppm)	Relative response factor	
	PID	FID
10	1.795	3.400
50	1.744	3.420
100	1.684	3.430
250	1.527	3.480
500	1.322	3.558
1000	1.041	3.713
2000	0.731	4.023
5000		4.953
7500		5.728
10000		6.503

7 - 24



7 - 25

Calibration Precision Performance Criteria

- Calibration precision test is performed by three analyses of zero gas and certified calibration gas. Acceptance criteria is +/- 10% of certified values

7 - 26

Calibration Precision Test

- **When:**
  - Before testing; Monthly
- **Materials Needed:**
  - Zero (<10 ppm VOCs) and calibration gas (certified within +/- 2%)

7 - 27

Calibration Precision Test

- **How:**
  - Calibration Precision = (Obser. value) – (Certified value)/ (Certified value)
  - Must be within 10%

7 - 28

7 - 29

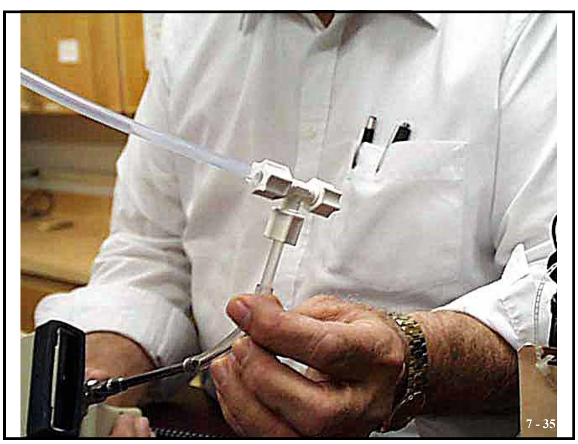
7 - 30

7 - 31

7 - 32

7 - 33

7 - 34



7 - 35

7 - 36

Response Time Performance Criteria

- Response time is performed during the calibration precision test and must meet a criteria of <30 seconds

7 - 37

7 - 38

Response Time Test

- When:
  - Before testing; at instrument modification
- How:
  - Introduce zero gas, then switch to calibration gas, measure time from switching to when 90% of the stable reading is obtained; repeat two additional times and average

7 - 39

Response Time Test

- Acceptance Criteria
  - Response time less than 30 seconds

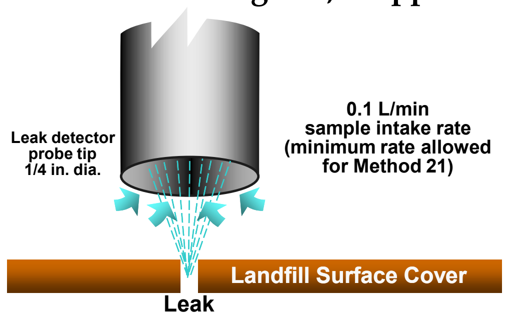
7 - 40

Limitation of FRM 21

- Different compounds react differently to different detectors
- Instrument probe intake rate
- Wind effects
- Pressure effects
- Temperature effects

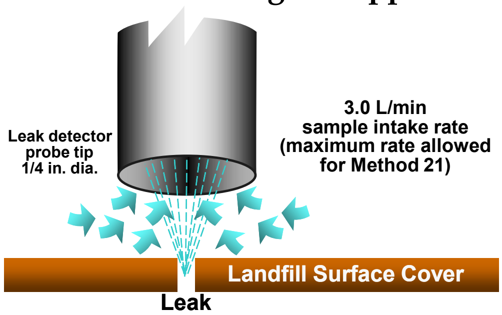
7 - 41

Meter Reading - 15,000 ppm



7 - 42

Meter Reading - 500 ppm



7 - 43

Surface Monitoring

- Surface emission monitoring must be performed in accordance with section 8.3.1 of Method 21 of appendix A of this part, except that the probe inlet must be placed within 5 to 10 centimeters of the ground. Monitoring must be performed during typical meteorological conditions.

9 - 44

Surface Monitoring

- **(1)** The portable analyzer must meet the instrument specifications provided in section 6 of Method 21 of appendix A of this part, except that "methane" replaces all references to "VOC".
- **(2)** The calibration gas must be methane, diluted to a nominal concentration of 500 parts per million in air.

9 - 45

Surface Monitoring

- **3)** To meet the performance evaluation requirements in section 8.1 of Method 21 of appendix A of this part, the instrument evaluation procedures of section 8.1 of Method 21 of appendix A of this part must be used.
- **(4)** The calibration procedures provided in sections 8 and 10 of Method 21 of appendix A of this part must be followed immediately before commencing a surface monitoring survey.

9 - 46

Manufacturers of Portable VOC Instruments

- **Thermo Environmental Instruments (TEI)/Foxboro**
  - **www.thermofisher.com**
- **Perkin-Elmer (PE) Photovac Company**
  - **www.perkinelmer.com**

Landtec SEM 5000 QED

Elkin Earthworks - Irwin

7 - 47

Manufacturers of Portable VOC Instruments

- **Bacharach**
  - **www.bacharachinc.com**
- **MSA**
  - **www.msanet.com**
- **Sensidyne**
  - **www.sensidyne.com**

7 - 48

Manufacturers of Portable VOC Instruments

- Hnu Systems
  - www.hnu.com
- AIM Safety USA
  - www.aimsafeair.com

7 - 49

Manufacturers of Portable VOC Instruments

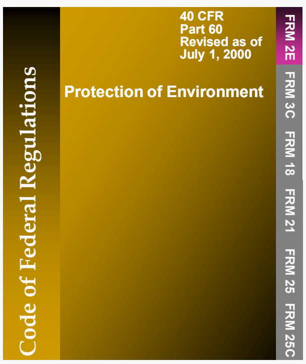
- CEA Instruments
  - www.ceainst.com
- Sentex Sensing Technology
  - www.sentex.com

7 - 50

Federal Reference Method 2E

Determination of Landfill Gas Production Flow Rate

8 - 2



8 - 3

Applicability

- Applies to measurement of landfill gas (LFG) production flow rate from municipal solid waste (MSW) landfills
- Used to calculate the flow rate of nonmethane organic compounds (NMOC) from landfills
- Also applies to calculating a site-specific “k” value

8 - 4

Principle

- Extraction wells are installed in a cluster of three, or at five locations dispersed throughout the landfill
- A blower is used to extract LFG from the landfill

8 - 5

Principle

- LFG composition, landfill pressures near the extraction well, and volumetric flow rate are measured, and landfill gas production flow rate determined

8 - 6

Apparatus

- Well drilling rig
- Material
  - Gravel
  - Bentonite
  - Backfill material

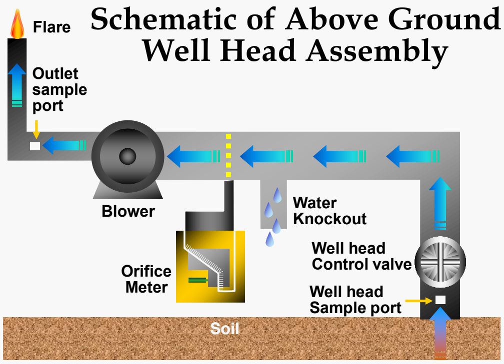
8 - 7

Apparatus

- Wellhead assembly
  - Control valve
  - Orifice meter/manometer
  - Blower
  - Sampling ports (Well head/outlet)

8 - 8

Schematic of Above Ground Well Head Assembly



8 - 9

Placement of Extraction Wells

- Single cluster of three (3) extraction wells in a test area (Waste known)
  - Near perimeter of site
  - Depth equal to or greater than the average depth of the landfill
  - Waste 2-10 years old

8 - 10

Placement of Extraction Wells

- Five (5) wells spaced over the landfill (waste unknown)
  - Divide landfill into five (5) equal areas and place extraction well at centroid of each area

8 - 11

Extraction Well Pipe Configuration

- PVC, HDPE, fiberglass, stainless steel or other materials of construction
- Minimum diameter of 0.075 meters (2.95”)

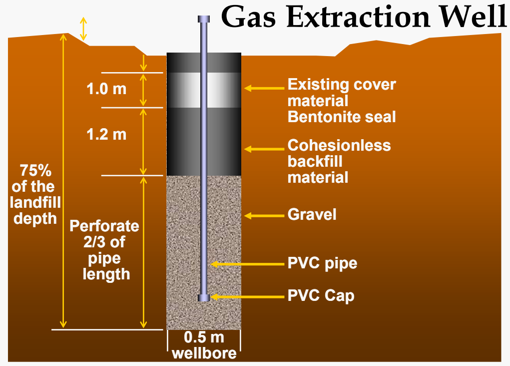
8 - 12

Extraction Well Pipe Configuration

- Bottom two-thirds of the pipe perforated
  - Holes/slots 1.0-centimeter diameter
  - Spaced 90 degrees apart every 0.1 to 0.2 meters

8 - 13

Gas Extraction Well



8 - 14

Extraction Well Pipe Placement

- Place in center of hole
- Backfill with gravel to 0.3 meters above perforation
- Add backfill material 1.2 meters thick
- Add layer of bentonite 1.0 meters thick
- Remainder cover material

8 - 15

Pressure Probe

- Pressure probes are used in the check for infiltration of air into the landfill and radius of influence
  - Shallow pressure probes used for determination of infiltration of air into landfill
  - Deep pressure probes used to determine the radius of influence

8 - 16

Pressure Probe Configuration

- PVC or stainless steel, 0.025 meter
- Bottom two-thirds of pipe perforated
  - Four 6-mm diameter holes
  - Placed 90 degrees apart
  - Every 0.15 meters

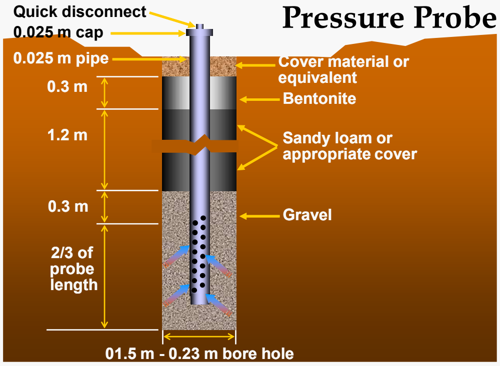
8 - 17

Pressure Probe Placement

- Shallow pressure probes placed in close proximity to cluster well
- Deep pressure probes
  - Along three radial arms from the extraction wells
  - Approximately 120 degrees apart
  - Distances of 3, 15, 30, and 45 meters from extraction wells

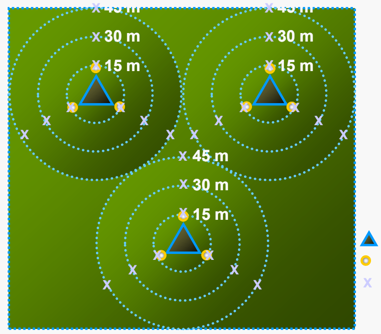
8 - 18

Pressure Probe



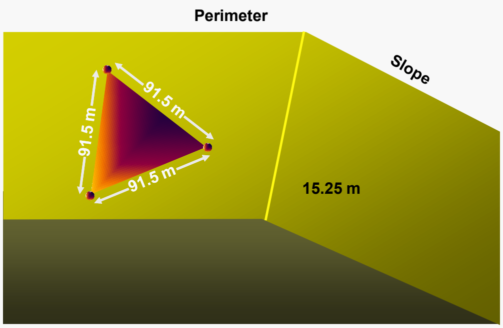
8 - 19

Cluster Well Configuration



8 - 20

Location of Cluster Wells



8 - 21

LFG Flow Rate Measurement

- Leak Check System:
  Measure nitrogen using FRM 3C at the well head and downstream of the flow measuring device. System is leak tight if difference is < 10,000 ppm

8 - 22

LFG Flow Rate Measurement

- LFG Flow Rate:
  Measure LFG flow rate using orifice meter and manometer continuously during testing

8 - 23

LFG Static Testing

- Purpose: Determine the initial condition of the landfill
- Procedure: Close the control valve on the well. Measure the gauge pressure (P_g) at each deep pressure probe and barometric pressure (P_{bar}) every 8 hours for 3 days

8 - 24

LFG Static Testing

- Calculate: $P_i = P_{bar} + P_g$
- Average all 8 hours reading for each well to record P_{ia}

8 - 25

Well Temperature and Static Flow Rate

- Measure the LFG temperature at each well head
- Measure static flow rate using Type S pitot tube at each well head

8 - 26

Short Term Testing

- The purpose of short-term testing is to determine the maximum vacuum that can be applied to the wells without infiltration of air into the landfill
  - Use blower to extract LFG from single well (others capped) at a rate at least twice the static flow rate

8 - 27

Short Term Testing

  - Check for infiltration of air into the landfill by measuring the temperature of the LFG at the wellhead, the gauge pressures of the shallow pressure probes, and LFG nitrogen using FRM 3C
- LFG concentration of nitrogen is > 20 %
- Any shallow probes have a negative gauge pressure

8 - 28

Short Term Testing

- LFG temperature > 55°C
- Increase the blower vacuum by 4 mm Hg, wait 24 hours, and repeat infiltration test
- Continue increasing blower vacuum by 4 mm Hg until infiltration occurs

8 - 29

Short Term Testing

- Then reduce blower vacuum until nitrogen < 20%, shallow probes are positive, or LFG temperature < 55°C
- This is the maximum vacuum at which infiltration does not occur
- At this maximum vacuum, measure P_{bar} every 8 hours for 24 hours
- Record LFG flow rate: Q_s

8 - 30

Short Term Testing

- Deep probe gauge pressures for all probes every 8 - hours: P_f
- Average 8 - hour readings of deep probes: P
- Compare initial average pressure (P_{ia}) to final average pressure (P_{fa})

8 - 31

Short Term Testing

- Determine furthermost point from the wellhead along each radial arm where $P_{fa} < P_{ia}$

8 - 32

Short Term Testing

- This is the distance of maximum radius of influence (ROI)
- Average ROIs to determine the average maximum radius of influence (R_{ma})
- Calculate depth (D_{st}) affected by the extraction well:
  - $D_{st} = WD + R_{ma}^2$

8 - 33

Short Term Testing

- Calculate void volume (V)
  - $V = (0.40)(R_{ma}^2)(D_{st})$
- Calculate total void volumes (V_v)
  - Sum of all V

8 - 34

Long Term Testing

- The purpose of long-term testing is to determine the methane generation rate constant, k
  - Set blower vacuum to previously determined highest vacuum rate acceptable without infiltration
  - Every 8 hours, sample LFG, measure gauge pressure at shallow pressure probes, the blower vacuum, the LFG flow rate, and check for infiltration

8 - 35

Long Term Testing

- Calculate Vt, the total volume of landfill gas extracted:

$$V_t = \sum_{i=1}^{n} (60)(Q_i)(T_{vi})$$

- Qi = LFG flow rate measured at orifice meter during the ith interval, m3 /min.
- tvi = Time of the ith interval (usually 8), hr.

8 - 36

Calculating NMOC mass emission rate

$$Q_t = \frac{2kL_oC_{NMOC}}{(5.256x10^{11})}\sum_{i=1}^{n} M_i e^{-kt_i}$$

k = Landfill gas generation constant, yr−1 .
L_o = Methane generation potential, m3 /Mg.
CNMOC = NMOC concentration, ppmv as hexane (CNMOC =Ct/6)
Mi = Mass of refuse in the ith section, Mg.
ti = Age of section i, yr

8 - 37

Determination of Gas Constituents for O2 and CO2

8 - 38

O_2 / $C0_2$

Method 3	Molecular Weight
Method 3A	Oxygen and Carbon Dioxide Concentrations - Instrumental
Method 3B	Oxygen and Carbon Dioxide Concentrations - Orsat Analyzer
Method 3C	Carbon Dioxide, Methane, Nitrogen and Oxygen Concentrations - Thermal Conductivity Detector

8 - 39

Federal Reference Method 3A

Determination of Carbon Dioxide and Oxygen from Stationary Sources (40 CFR 60, Appendix A)

8 - 40

8 - 41

Applicability

- This method applies to the analysis of carbon dioxide (CO_2) and oxygen (O_2) in samples from Stationary sources when specified in an applicable subpart

8 - 42

Principle

- A sample is continuously extracted from the effluent stream: a portion of the sample stream is conveyed to an instrumental analyzer for the determination of CO_2 and O_2.

8 - 43

Apparatus

- Gas analyzer to continuously determine the O2 and CO2 concentration in the sample gas stream. The analyzer must meet specifications identified in Method 7E, Section 13
- Sample probe (if applicable), sample transport line, calibration gases and data recorder.

8 - 44

Calibration and Linearity Gases

- Standard cylinder gas mixtures for each compound of interest with at least three (3) concentration levels spanning the range of sample concentration.

8 - 45

Measurement System Performance Specifications

- Analyzer Calibration Error. Less than 2% of the span for calibration gases
- Sampling System Bias. Less than 5% of the span for calibration gases.

8 - 46

Measurement System Performance Specifications

- Calibration Drift.

  Less than 2% of the span for calibration gases.
- Sampling System Bias.
- Less than 5% of the span for calibration gases.

8 - 47

Measurement System Performance Specifications

- Calibration Drift.

Less than 3% of the span over the period of each run.

- Interference Check.

Less than 2% of the span for each test gas.

8 - 48

Measurement System Performance Specifications

- Calibration Concentration Verification. Introduce calibration gases into analyzer, make no adjustments (+/- 2%)
- Interference Response. Conduct an interference response test of the analyzer prior to initial field test.

8 - 49

Emission Test Procedure

- Select the sampling site
- Extract sample at the same flow rate as used during calibratiom
- Sample for 5 minutes obtaining a constant reading
- After sampling, perform zero and calibration drift test

8 - 50

Concentration of Sample Components

$$C_{Gas} = \left(C_{Avg} - C_M\right)\frac{C_{MA} - C_{OA}}{C_M - C_O} + C_{MA} \qquad \text{Eq. 7E-5a}$$

$$C_{Gas} = \left(C_{Avg} - C_O\right)\frac{C_{MA}}{C_M - C_O} \qquad \text{Eq. 7E-5b}$$

CAvg = Average unadjusted gas concentration indicated by data recorder for the test run, ppmv.
CD = Pollutant concentration adjusted to dry conditions, ppmv.
CDir = Measured concentration of a calibration gas (low, mid, or high) when introduced in direct calibration mode, ppmv.
CGas = Average effluent gas concentration adjusted for bias, ppmv.
CM = Average of initial and final system calibration bias (or 2-point system calibration error) check responses for the upscale calibration gas, ppmv.
CMA = Actual concentration of the upscale calibration gas, ppmv.
CNative = NOX concentration in the stack gas as calculated in section 12.6, ppmv.
CO = Average of the initial and final system calibration bias (or 2-point system calibration error) check responses from the low-level (or zero) calibration gas, ppmv.
COA = Actual concentration of the low-level calibration gas, ppmv.
CS = Measured concentration of a calibration gas (low, mid, or high) when introduced in system calibration mode, ppmv.

8 - 51

Federal Reference Method 3C

Determination of Carbon Dioxide, Methane, Nitrogen, and Oxygen from Stationary Sources (40 CFR 60, Appendix A)

8 - 52

8 - 53

Applicability

- This method applies to the analysis of carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2), and oxygen (O_2) in samples from municipal solid waste landfills and other sources when specified in an applicable subpart

8 - 54

Principle

- A portion of the sample is injected into a gas chromatograph (GC) and the CO_2, CH_4, N_2, and O_2 concentrations are determined by using a thermal conductivity detector (TCD) and integrator

8 - 55

Applicability

- This method applies to the analysis of carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2), and oxygen (O_2) in samples from municipal solid waste landfills and other sources when specified in an applicable subpart

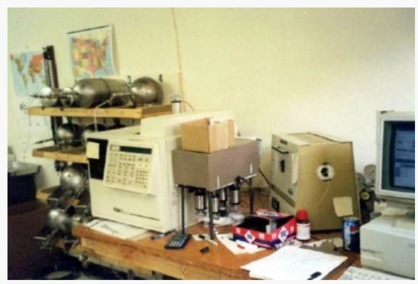
8 - 56

Apparatus

- Gas Chromatography equipped with separation column, sample loop, conditioning system, and thermal conductivity detector
- Recorder, tubing, regulators and adsorption tubes to remove any oxygen in the carrier gas

8 - 57

GC System and Analytical Apparatus



8 - 58

Calibration and Linearity Gases

- Standard cylinder gas mixtures for each compound of interest with at least three (3) concentration levels spanning the range of sample concentration

8 - 59

Sample Collection

- Direct Injection
- Tedlar® Bag
- Whole Air Flask/Canister

8 - 60

Whole Air Flask/canister at Extraction Well

8 - 61

Analytical System Standardization

- Optimize GC system according to manufacturer's specifications
- Linearity Check and Calibration
  - Three calibration gases over the range of suspected sample concentration (This initial check may also serve as the initial instrument calibration)

8 - 62

Analytical System Standardization

- Plot linear regression of concentration vs. area values to obtain relative response to each compound

8 - 63

Analytical System Standardization

- Single Point Calibration Check
  - Use standard calibration gas which is within 20% of the sample component concentration

8 - 64

Sample Analysis

- Purge sample loop with sample
- Analyze each sample in duplicate
  - Peak areas should agree within 5% of their average

8 - 65

Method 3C Calculations

- Moisture content in the sample
  - $B_w = P_w/P_{bar}$
- Compound concentration
  - $C = A/R(1-B_w)$
  - Pw = Vapor pressure of H_2O (from Table 25C-1), mm Hg.
  - R = Mean calibration response factor for specific sample component, area/ppm.

8 - 66

Concentration of Sample Components

$$C = \left(\frac{\left(\frac{P_{tf}}{T_{tf}}\right)}{\left(\left(\frac{P_t}{T_t}\right) - \left(\frac{P_{ti}}{T_{ti}}\right)\right)} \right) * \left(\frac{A}{R(1 - B_w)} \right)$$

Pt = Gas sample tank pressure after sampling, but before pressurizing, mm Hg ab
Ptf = Final gas sample tank pressure after pressurizing, mm Hg absolute.
Pti = Gas sample tank pressure after evacuation, mm Hg absolute
t = Sample tank temperature at completion of sampling, °K.
Tti = Sample tank temperature before sampling, °K.
Ttf = Sample tank temperature after pressurizing, °K.

8 - 67

Federal Reference Method 25

Determination of Total Gaseous Nonmethane Organic Emissions as Carbon

9 - 1

9 - 2

Applicability

- Method 25 applies to the measurement of volatile organic compounds (VOCs) as total gaseous nonmethane organics (TGNMO) as carbon in source emissions
- This method is not applicable for the determination of organic particulate matter

9 - 3

Method 25

- Applicability
  - For measuring control efficiency from coating operations including auto, appliance, metal furniture, metal coil coating flares and landfill emissions

9 - 4

Method 25

- Not Applicable
  - For measuring concentrations of VOCs or mass emissions of VOCs from sources whose concentrations are < 50 ppm (as Carbon)

9 - 5

Method 25

- Not Applicable
  - For measuring emissions from sources whose principal solvents are chlorinated hydrocarbons
  - Generally, for any situation were a simpler procedure is more accurate

9 - 6

Method 25 Principle

- A gas sample is withdrawn from the source at a constant rate through a chilled condensate trap by means of an evacuated sample tank

9 - 7

Method 25 Principle

- TGNMO are determined by combining the analytical results obtained from independent analysis of the condensate trap and sample tank fraction

9 - 8

Method 25 Interference

- Organic particulate matter will interfere with the analysis; therefore, a particulate filter may be required

9 - 9

Method 25 Advantages

- Gives constant results from source to source whether sample composition is known or not
- Sample train does require heated probe and filter, but is less complicated than FRM 5 hardware

9 - 10

Method 25 Disadvantages

- Will not yield true mass emission rate nor instantaneous results
- No real time data (sample must be returned to laboratory for analysis)
- High moisture and CO_2 together can cause interference
- $(\%CO_2)(\%H_2O)$ >100 gives potential high bias

9 - 11

Method 25 Summary

- Withdraw emission sample from stack through chilled condensate trap into evacuated cylinder
- Analyze contents of trap and cylinder separately
- Oxidize organic content of trap to CO_2
- Reduce to methane, measure with FID

9 - 12

Method 25 Summary

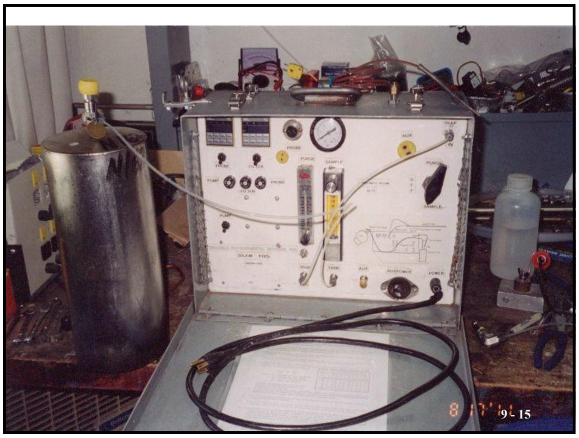
- Inject portion of cylinder sample into GC to separate non-methane organics, oxidize NMO to CO_2, reduce to methane, and measure with FID
- Combine results and report as total gaseous nonmethane organics

9 - 13

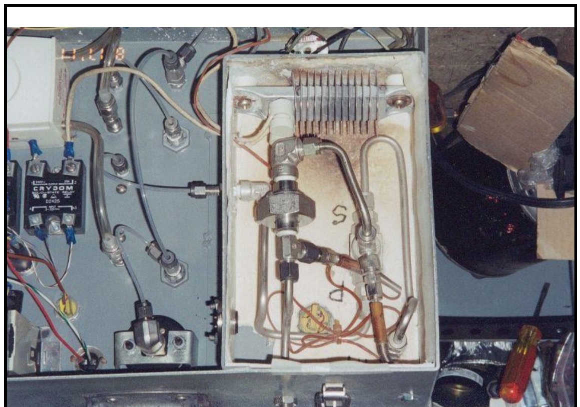
Method 25 Apparatus

- Sampling System
  - Probe
  - Condensate trap
  - Flow control system
  - Sample tank

9 - 14



9 - 15



9 - 16

Calibration of Sampling System

- Sample tank volume
- Volume of sampling train from probe tip to sample tank valve

9 - 17

Calibration of Sampling System

- Sample tank: Within 5 g or 5 mL
- Sample train volume: No limits
- Rotameter: Not calibrated
- Thermometers: Within 3°C of true value
- Barometer: Within 0.1 in. Hg of mercury-in-glass barometer

9 - 18

Method 25 Sampling Train Preparation

- Leak check the meter box
- Assemble the probe, trap, and canister
- Leak check the entire sampling train

9 - 19

Method 25 Train Preparation

- Evacuate sample tank to 10 mm Hg. Record on field test data sheet (FTDS)
- Measure tank vacuum

9 - 20

Method 25 Train Preparation

- Immerse condensate trap in dry ice
- Plug probe tip

9 - 21

Method 25 Train Preparation

- Evacuate sampling system from probe tip to valve to 10 mm Hg
- Close purge valve, turn off pump, wait 10 minutes
- Record D P

9 - 22

Method 25 Train Preparation

- Calculate maximum allowable pressure change based on leak rate of 1% and compare to measured D P
- Record findings on FTDS

9 - 23

Method 25 Sampling

- Mark probe for point of average stack gas velocity (probe $\leq$ 36 in. as specificed in FRM 25)
- Check dry ice level
- Calculate flow rate, record time, set flow rate, probe temp, and filter

9 - 24

Method 25 Sampling

- Position probe tip perpendicular to source gas flow
- Purge sampling train, then adjust flow rate

9 - 25

Method 25 Sampling

- Record sample tank vacuum, flow meter settings, and temperatures at 5 - minute intervals on FTDS
- Sampling must be ±10% over duration of sampling rate between 60-100 mL/min
- After sampling, close purge valve, record final readings

9 - 26

Method 25 Sampling

- Recover components, disconnect sample tank, record tank vacuum
- Disconnect condensate trap, seal both ends
- Record final readings on FTDS and chain-of-custody
- Pack trap in dry ice during storage and shipping

9 - 27

Method 25 Sample Analysis

- Condensables in the trap are vaporized and oxidized to CO_2 and collected in an evacuated tank
- The CO_2 is then injected into the NMO analyzer, reduced to methane, and detected with an FID

9 - 28

Method 25 Sample Analysis

- Non Condensables
  - The sample in the original tank is injected into the analyzer
  - Methane, CO, and CO_2 are separated, and the remaining compounds are then back-flushed, oxidized to CO_2, reduced to methane and detected with an FID

9 - 29

Method 25 Apparatus

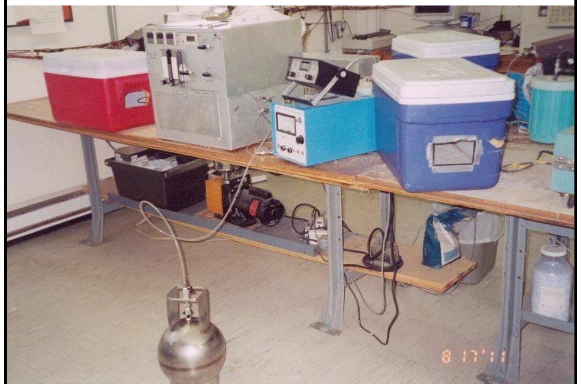
- Analytical System
  - Oxidation system for recovery and conditioning of condensate trap contents
    - Heat source
    - Oxidation catalyst
    - Non-dispersive infrared analyzer
    - Intermediate collection vessel (ICV)

9 - 30

Method 25 Apparatus

- NMO Analyzer
  - GC with back-flush capability
  - Oxidizing/reducing catalyst
  - FID

9 - 31



9 - 32

Initial Performance Check of Condensate Recovery and Conditioning Apparatus

- Carrier gas and auxiliary oxygen blank
- Catalyst efficiency check
- System performance check

9 - 33

Daily Performance Tests

- Condensable organic recovery system
  - Leak test
  - System background test
  - Oxidation catalyst efficiency test
- NMO analyzer daily calibration
  - CO_2 response calibration
  - NMO response calibration

9 - 34

Condensable Organic Fraction Recovery

- Recovery of condensable organics is accomplished in two stages
  - Condensate trap is purged of CO_2 while cooling the trap in dry ice
  - Condensate organics are volatilized and converted catalytically to CO_2 which is collected in an intermediate collection vessel (ICV) for analysis

9 - 35

Condensable Organic Fraction Recovery

- Trap purge and sample tank pressurization
  - Obtain sample tank and condensate trap
  - Set zero air flow to 100 mL/min
  - Attach the sample tank to the condensate trap recovery system

9 - 36

Condensable Organic Fraction Recovery

- Measure sample tank pressure
- Immerse the condensate trap in crushed dry ice
- Observe IR response to CO_2 to minimum level of < 5 ppm
- Pressurize sample tank to 1060 mm Hg absolute pressure and detach

9 - 37

Condensable Organic Fraction Recovery

- Recovery of condensible organics
  - Attach an ICV to the trap recovery system and evacuate to 10 mm Hg
  - Set auxiliary oxygen flow to 150 mL/min
  - Switch 4-port valve to collect position

9 - 38

Condensable Organic Fraction Recovery

- Remove condensate trap from dry ice and allow to warm to room temperature
- Heat trap by placing it in a furnace at 200°C

9 - 39

Condensable Organic Fraction Recovery

- Recovery of condensable organics
  - After NDIR analyzer indicates a CO_2 concentration of < 10,000 ppm, begin heating the tubing that connects the condensate trap to the oxidation catalyst with a heat gun

9 - 40

Condensable Organic Fraction Recovery

- Continue trap heating and purging until the CO_2 concentration is below 10 ppm
- Pressurize the ICV to approximately 1060 mm Hg

9 - 41

9 - 42

9 - 43

Method 25 Analysis

- ICV Analysis
  - Attach the ICV to the 10-port gas sampling valve
  - Purge sample loop
  - When detector response returns to near baseline after CO_2 peak, back-flush and increase column oven temperature

9 - 44

Method 25 Analysis

- After detection of any NMOC, return column oven temperature to 85°C
- Record the CO_2 peak area and NMO peak area
- Repeat analysis two additional times

9 - 45

Method 25 Analysis

- Sample Tank
  - Inject triplicate samples from the sample tank and record the values obtained for nonmethane organics only
  - Perform three analyses and average the NMO values

9 - 46

Method 25 Calculations

- Sample volume
- Noncondensable organics
- Condensable organics
- Total gaseous nonmethane organics (TGNMO)
- Percent recovery
- Relative standard deviation

9 - 47

Method 25 Guide

- Make sure tanks, traps, and sample trains are clean
- Analyze confirmation preferred
- Leak check sampling trains in the field, even though they are checked in the lab

9 - 48

Method 25 Guide

- Leak check cold (minimize heating/re-cooling system)
- Leak check before adding trap
- Leak check canisters before use in field
- Leak check with rotameter completely open

9 - 49

Method 25 Guide

- Setup sampling train properly
- DO NOT over-tighten the filter or the swage fittings
- If there is a leak, go to last fitting disturbed
  - Use logical approach to find leak
  - Isolate specific areas in the sample train

9 - 50

Method 25 Guide

- Get most accurate pre-test and post-test barometric pressures, tank vacuums, and temperature possible
- Used in sample volume

9 - 51

Method 25 Guide

- Use small pellets of dry ice around the trap to increase contact to trap organics
  - This will generate better results (esp. oxygenated organics)

9 - 52

Method 25 Guide

- Monitor both sample flow and tank vacuum with the rotameter and gauge on the unit
- Vacuum gauge is not accurate, but used as an indicator of proper sampling

9 - 53

Method 25 Guide

- Take care that the brass caps from the traps don't come into contact with pump oil, vacuum grease, or other contaminants
- Use tags to identify the tank/trap pairing, as well as noting the pairings on the sample data sheet

9 - 54

Method 25 Guide

- Seal both arms of the trap with the brass caps and pack the cooler with sufficient dry ice to ensure the temperature is maintained until receipt at the labs

9 - 55

Method 25 Guide

- Perform Method 25 gas audits prior to field sampling to minimize carryover of contaminants from a dirty sampling train
- If sampling blanks are part of the program, a preferred method is to collect a clean air sample over a one hour period using the project sampling train components

9 - 56

Method 25 Guide

- If high concentrations are expected, then collect only 3.5 L sample
- If low concentrations are expected, then collect larger volume of gas

9 - 57

Method 25 Guide

- If very high moisture is expected, then add an ice water second trap in front of the cryogenic trap to prevent freezing water from plugging the sample flow

9 - 58

Method 25 Guide

- However, this increases analytical cost and may increase the positive bias from trapping CO_2
- This approach does appear to limit sampling problems

9 - 59

Federal Reference Method 25A

Determination of
Gaseous Organic Concentration
(Flame Ionization)

9 - 60

Applicability

- This method is applicable to the measurement of total gaseous organic concentration of vapors consisting primarily of alkanes, alkenes, and/or arenes (aromatic hydrocarbons)
- Only measures C-H bond very well and analytes that can generate a response factor (RF)

9 - 61

Applicability

- Results from the use of FRM 25A are expressed in terms of volume concentration of propane (or other appropriate organic calibration gas) or in terms of carbon

9 - 62

Applicability

- Results from FRM 25A are measured on a wet basis and the concentration must be adjusted for the percent moisture in the sample gas stream for the purpose of emission calculations

9 - 63

Applicability

- FRM 25A "…*can only be used where an appropriate response factor for the stack gas can be determined"*

9 - 64

Instrument Response Factors (RF)

- The instrument response factor for the compound of interest is determined by:
  - $RF = \frac{\text{Actual Concentration}}{\text{Instrument Observed Concentration}}$
  - Typical RF:
    - Benzene: 0.29 (i.e., actual conc. Was 2.9 ppm yet the instrument read 10 ppm)
    - Chloroform: 9.28
  - M25A requires RF determination

9 - 65

Agency Example RF Application

(Surface Coating Operation)

- Four analytes which you know % of solvent used in mixture
- Standard prepared with that same percent ratio in mixture in gas std.
- Response of analyzer in ppm as carbon
- Concentration of gas stream is determined by dividing by RF

9 - 66

Applicability

- The concentration is expressed in terms of propane (or other appropriate organic calibration gas) or in terms of carbon
- Measurement is made on a wet bases and emissions must be adjusted accordingly to dry bases
- Span value of the analyzer is usually 1.5 to 2.5 times the applicable emission limit

9 - 67

FRM 25A Items

- Calibration for FRM 25A should be done using EPA Traceability Protocol gas standards, preferably propane
- The entire sampling system prior to the flame ionization detector (FID) should be heated to the higher temperature of 248 +/- 25 °F or stack temperature. Heating above 400 °F is not required

9 - 68

FRM 25A Items

- A system bias check is required and is performed by introducing the bias check standard directly into the FID and then through the entire sampling system, excluding the probe. Results must agree within 5 % to be acceptable

9 - 69

FRM 25A Items

- The bias check standard must be representative of the effluent (i.e., boiling point, solubility, chemical reactivity etc.). Propane may be used if effluent is unknown.

9 - 70

FRM 25A Items

- For the bias test, propane should be used at the following processes:
  - Incinerators, boilers, asphalt plants, cement plants and resource recovery facilities.
- For the bias test, propane should NOT be used at the following processes:
  - Bakeries (using yeast),ethylene oxide sterilizers, chemical manufacturing facilities (HON/SOCMI), surface coating operations, and graphic arts operations

9 - 71

FRM 25A Items

- Calibration error test must be performed within 2 hours of start of testing
  - Introduce zero and high-level standard, adjust
  - Introduce low and mid level standard, no adjustment. Criteria of 5 %
- Perform response time test at same time as calibration error test for zero and high level standard. Repeat 3 times and record. Typically < 1 minute

9 - 72

FRM 25A Items

- Drift determination is determined each hour during the test
  - Introduce zero and mid-level gas standards
  - Criteria: < 3 %
- FRM 25A sampling system must be leak checked prior to monitoring
- Location of sampling point can be a single point (> 1.5 meters from inside wall of stack) or racked probe (16.7, 50, 83.3 %)

9 - 73

Wet Bases to Dry Bases

- Wet bases measurement emissions to dry bases measurement emissions:
  - $C_{s(dry)} = \frac{C_{s(wet)}}{(1-B_{ws})}$
  - $C_{s(dry,STP)} = \frac{C_{s(wet)}}{(1-B_{ws})} \text{ x } \frac{(T_s)(P_{std})}{(T_{std})(P_s)}$

9 - 74

Principle

- A gas sample is extracted from the source through a heated sample line and filter to a total hydrocarbon analyzer (THC) containing a flame ionization detector (FID)
- All components kept at 250 °F (121 °C)

9 - 75

Principle

- Sampling is performed on a continuous, real-time basis with results proportional to the carbon content of the sample stream passing through the detector on a wet bases
- FID is linear from 0-10,000 ppm (If higher concentrations, then use dilution system)
- Method 25A is good up to about 40 % moisture in the stack gas

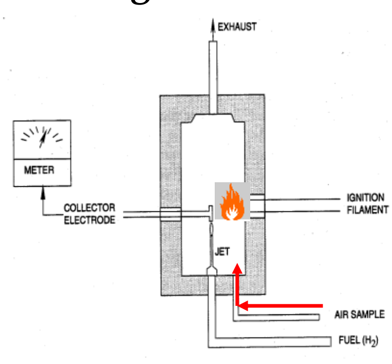
9 - 76

FID Theory

- Basic Theory:
  - Sample is introduced into an ionization chamber and burned
  - Process separates free ions
  - Free ions are attracted to a collecting electrode
  - Collection of the ions results in an increased current which is proportional to the concentration of the compound
  - By-products are H_2O and CO_2

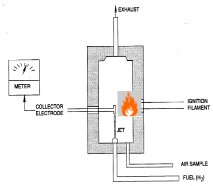
9 - 77

Diagram of FID



9 - 78

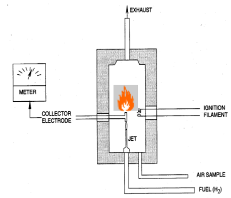
Flame Ionization Detection



- Advantages
  - Wide dynamic and linear range (0-10,000 ppm)
  - Highly sensitive to hydrocarbon vapors
  - Very stable and repeatable
  - Unaffected by ambient levels of CO, CO_2 and water vapor

9 - 79

Flame Ionization Detection



- Disadvantages
  - Requires oxygen > 16% to operate
  - Total hydrocarbon detector - not specific

9 - 80

Principle

- FRM 25A results are measured on a wet basis and the concentration must be adjusted for the percent moisture in the sample gas stream for purposes of emission calculations

9 - 81

Principle

- In general alkanes, alkenes, and aromatics are the most appropriate compound groups for FRM 25A sampling and analysis
- May also be used on C, H & O compounds. Ethanol gives ~ 60% signal to that of propane, but can still be used for ethanol

9 - 82

FRM 25A Limitations

- Sensitivity greatest for the alkane, alkene, and aromatic organic compounds
- FRM 25A can only be used in situations where an appropriate response factor for the stack gas constituents can be determined

9 - 83

FRM 25A Limitations

- Gas streams with high moisture (> 40%) can affect response of the FID
- Limitations of the FID. FID response is different for different analytes
- Large quantities of methane present gives questionable results
- Sample gas needs O_2 (> 16 %) for combustion in the FID

9 - 84

FRM 25A Sampling System

- Sample Probe: A heated (> 250°F) stainless steel, three-hole rake type probe. Holes should be 4 mm diameter or smaller and located at 16.7, 50, and 83.3% of the equivalent stack diameter
- Alternatively, a single opening probe may be used so that a gas sample is collected from the centrally located 10% area of the stack cross-section

9 - 85

Options for Sampling Point

- Single point in centroid of stack
- Single point at average velocity of stack gas
- Rake probe (i.e., 16.7%, 50%, and 83.3% of the equivalent stack diameter
  - Therefore, FRM 2 needed to determine cyclonic flow and velocity of stack gas

9 - 86

FRM 25A Sampling System

- Sample Line: Heated (> 250°F) stainless steel or Teflon® tubing
- All components must be heated > 250 °F so moisture and organics don't drop out of the gas stream
  - Check unions for cold spots
  - Check for unheated transfer line
  - Check for sudden spiking at steady state conditions
  - Check for unheated filter

9 - 87

Sampling System

- Calibration Valve Assembly: A heated (> 250°F) three-way valve at exit of probe assembly to direct the zero and calibration gases to the analyzer
- Particulate Filter: An in-stack or an out-of-stack heated (> 250°F) glass fiber filter assembly
- Pump: A heated (> 250°F) leak-free diaphragm type

9 - 88

Sampling System

- Organic Concentration Analyzer: A heated (> 250°F) total hydrocarbon analyzer (THC) with a flame ionization detector (FID)
- Recorder: A strip-chart, digital recorder, or computer for recording measurement data

9 - 89

FRM 25A Gases

- Fuel: 40% H_2/60% He or 40% H_2/60% N_2
- Zero Air: High purity air with less than 0.1 ppmv of organic material (propane or carbon equivalent)
  - Most systems use 100% H_2 as the fuel which makes for a hotter flame

9 - 90

Gases

- Calibration Gases (i.e., propane in air/N_2)
  - Low-level calibration gas: An organic calibration gas with a concentration equivalent to 25 to 35% of the applicable span value
  - Mid-level calibration gas: An organic calibration gas with a concentration equivalent to 45 to 55% of the applicable span value

9 - 91

Gases

- High-level calibration gas: An organic calibration gas with a concentration equivalent to 80 to 90% of the applicable span value

(Note: Use hydrocarbon/air standards; Propane/N_2 may yield inaccurate results!)

9 - 92

Steps to Perform An Analysis

- Calibration gases are NIST traceable! (Protocol 1)
- Leak Check System not mandatory but suggested!
- Calibration Error Test (With Propane): +/- 5% of calibration gas value

9 - 93

Steps to Perform An Analysis

- Response Time Test: 1-2 minutes; traditionally < 1 min; No specifications in FRM 25A
- Calibration Drift (Zero/Mid-span Gas)Test (No adjustments allowed to analyzer): +/- 3% of span value

9 - 94

Pre-test Requirements

- Sampling Site: Located as required by the specific regulations (i.e., exhaust stack, inlet line etc.)
- Shall be located to meet the testing requirements of Method 1

9 - 95

Pre-test Requirements

- Assemble the sampling system following manufacturer's specification
- Prepare sample interface from stack to extraction system
- Make system operable

9 - 96

Pre-test Requirements

- All delivery pressures of the gases to the THC/FID system <u>must be maintained at the same value used during calibration and sampling</u>

9 - 97

Remember Sampling Point Options!

- Single point in centroid of stack
- Single point at average velocity of stack gas
- Rake probe (i.e., 16.7%, 50%, and 83.3% of the equivalent stack diameter
  - Therefore, FRM 2 needed to determine cyclonic flow and velocity of stack gas

9 - 98

Calibration of M25A

- Calibration of THC/FID Analytical System: Generate a series of high, mid, and low range calibration gases of known concentrations spanning the linear range of the FID and introduce at the calibration valve assembly to the THC/FID
  - The analytical range must be chosen so that the source THC limit is 10 to 100% of the range
  - Calibration must be done on-site to determine RFs

9 - 99

Second Step To Perform An Analysis

- Calibration Error Test (Response to True Value):
  Perform a calibration error test (within 2 hours of the start of the test) by introducing the zero and high level calibration gases to the analyzer

9 - 100

Pre-test Calibration Error

- Calibration
  - The calibration gases are usually propane in air, propane in nitrogen, or methane in air or nitrogen
  - Perform three injections each of the calibration gases
  - Calibration gases must be NIST traceable

9 - 101

Pre-test Calibration Error

- Calibration
  - Generate calibration curve from the three injections performed in the calibration of the analytical system
  - Develop a “calibration factor” for each level of the injected calibration gases (the calibration factor should fall between 0.95 and 1.05 to be acceptable)

9 - 102

Pre-test Calibration Error

- Inject zero and high level (80-90 % of span value) at the calibration valve
- Adjust the analyzer output to the appropriate levels
- Introduce the mid and low level calibration gases
- Make no adjustments to the analyzer
- If system is linear, differences should be < 5%

9 - 103

Pre-test Calibration Error

- If can't meet < 5% of the calibration gas concentration value, then system must be replaced or repaired
- No adjustments can be made to the system after the calibration error test and before the calibration drift test
  - If adjustments are required, perform the calibration drift test prior to the adjustments and repeat the calibration drift test after the adjustments

9 - 104

Third Step To Perform An Analysis

- Response Time Test: Response time test is used to document response of gases by the THC/FID analytical system
  - Introduce zero gas at the calibration valve assembly
  - When the system output has stabilized, switch quickly to the high level calibration gas

9 - 105

Pre-test Requirements

- Record the time from the concentration change to the measurement system (no limit specified, just determine)
- Repeat the test three times
  - Just record results
- Response time should be < 1 minute, but can be 1-2 minutes
  - FRM 25A does not specify limit

9 - 106

Fourth Step To Perform An Analysis: Sampling

- Purge the sample system for a period of time longer than the response time of the system
- Mark the start time on the data recorder after purging. Remember, all delivery pressures of the gases to the THC/FID system <u>must be maintained at the same value used during calibration and sampling</u>
- <u>Begin sampling!!!</u>

9 - 107

Fifth Step To Perform An Analysis: Post-test

- Calibration Drift Determination: Immediately following completion of the test period (and hourly during the test), perform a calibration drift test
  - Reintroduce the zero and mid level calibration gases, one at a time, to the measurement system at the calibration valve

9 - 108

Post-Test Procedures

- Make no adjustments to the instrument, just record response
- If drift exceeds 3% (span value) for either gases, invalidate the test results preceding the check
  - If you fail drift test during run, then void sample to that point from the last acceptable drift test, recalibrate, and then continue!

9 - 109

Organic Concentration Calculations

- Calculated as ppm_v as carbon

$$C_c = K\, C_{measured}$$

Where:

K = 1 for methane
K = 2 for ethane
K = 3 for propane
K = 4 for butane
K = Appropriate response factor for other organic calibration gases

9 - 110

Method 25A Notes

- The use of Method 25A usually must be justified to regulatory agencies instead of using Method 25. Key points would be:
  - Expected concentration < 50 ppm
  - VOCs known to consist of C and H
  - $(CO_2)(H_2O) > 100\ \%$
- Set-up instrument in environmentally controlled room to minimize instrument drift

9 - 111

Method 25A Notes (Contd)

- To minimize condensation of VOCs in the analytical system, keep at least 10 °F hotter than rest of system
- Protocol 1 standard should be used for calibration, but other standards allowed if manufacturer certified accurate is 2 %
- Void test run if using expired standards….but!

9 - 112

Method 25A Notes (Contd)

- The entire sampling system (probe, heated sample lines, valves and manifolds) must be maintained at stack temperature or 250 °F (May go hotter/Web Offset Presses..350 °F)
  - Actual temperature of each component may want to be recorded every 15 minutes and included in final test report

9 - 113

Method 25A Notes (Contd)

- Agency may require a system bias check conducted with a certified standard that has properties (boiling point, water solubility, and reactivity) similar to the effluent as a whole. *Propane is not normally acceptable by regulatory agencies!*
  - Concentration of the system bias check standard must be similar to the concentration of the stack

9 - 114

Method 25A Notes (Contd)

- The analyzer temperature and pressure must be the same during sampling as it was during calibration
- Pollutant concentration must be measured on a wet basis and reported on a dry bases
- Any run in which the average VOC concentration exceeds the span must be voided

9 - 115

Method 25A Notes (Contd)

- For Destruction Efficiency (DE) Testing:
  - The same sampling method should be used; The outlet test location determines the method (i.e., concentration, % H_2O etc.)
  - The results (lbs/hour) at both the inlet and outlet must be on the same bases (as propane or as VOCs)

9 - 116

Method 25A Notes (Contd)

- The actual emissions should be determined if at a VOC coating source:

Emission Rate = {(Coating Usage)(VOC Content)(1-DE)(CE)} + {(Coating Usage)(VOC Content)(1-CE)}

9 -117

Federal Reference Method 25C

9 - 118

9 - 119

Applicability

- This method is applicable to the sampling and measurement of nonmethane organic compounds (NMOC) as carbon in MSW landfill gases

9 - 120

Principle

- In operation, a sample probe that has been perforated at one end is driven or augured to a depth of 1.0 meter below the bottom of the landfill cover
- A sample of the landfill gas is extracted with an evacuated cylinder

9 - 121

Principle

- The NMOC content of the gas is determined by injecting a portion of the gas from the evacuated cylinder into a gas chromatographic column to separate the NMOC from CO, CO_2, and CH_4

9 - 122

Principle

- The NMOC from the separation is oxidized to CO_2, reduced to CH_4, and measured by a flame ionization detector (FID)

9 - 123

FRM 25C Sampling System

- Probe: Stainless steel with the bottom third perforated. Must be long enough to go a minimum of 1 meter below landfill cover
- Rotameter: With flow control valve (< 500 mL/min)
- Sampling valve: Stainless steel

9 - 124

FRM 25C Sampling System

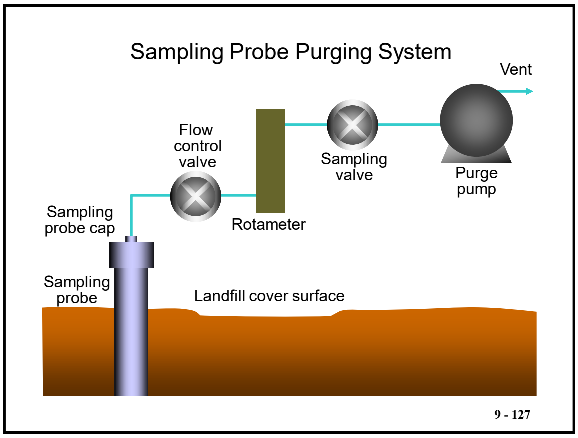
- Pressure gauge: U-tube mercury manometer
- Purge pump: Capable of purging probe
- Vacuum pump: Capable of evacuating to an absolute pressure of 10 mm Hg

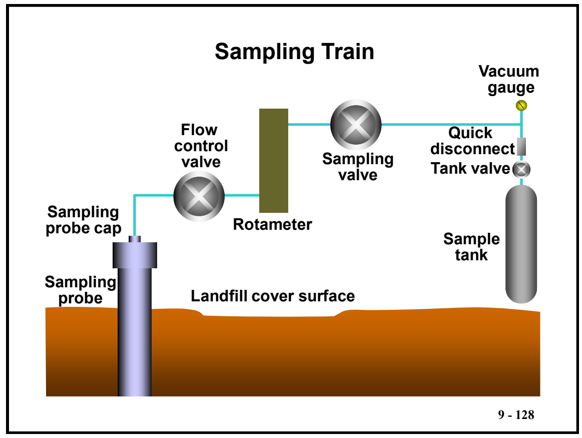
9 - 125

FRM 25C Sampling System

- Sampling tank: Stainless steel or aluminum cylinder with a minimum volume of 4 liters and equipped with a stainless-steel sample tank valve

9 - 126





Tank Sampling Procedure

- **Sample Tank Evacuation: Evacuate to 10 mm Hg absolute (field/laboratory), set aside for 60 minutes, check vacuum, no change; acceptable**

9 - 131

Tank Sampling Procedure

- **Sampling**
  - **Evacuate/pressurize sampling tank three time with final vacuum of 325 mm Hg; set aside**
  - **Assemble sample probe, flow control valve, rotameter and purge pump**

9 - 132

Pilot Probe Sampling Procedure

- Sample Probe Installation
  - Pilot Probe Procedure:
    - Use post driver to 1 meter below landfill cover
    - Insert sample probe
    - Seal with bentonite
    - Cap

9 - 133

Pitot Probe Sampling Procedure

- Purge at least 2 probe volumes at flow rate of 500 mL/min
- Replace purge pump with sample tank

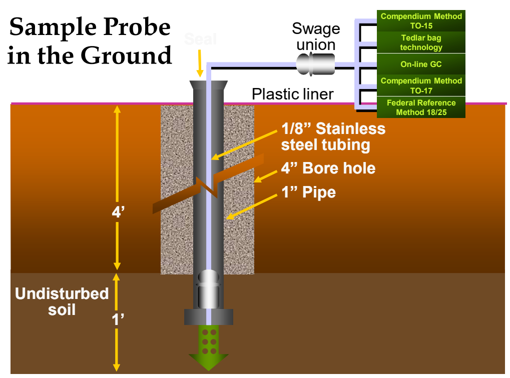
9 - 134

Pilot Probe Sampling Procedure

- Auger Procedure:
  - Drill hole to 1 meter below landfill cover
  - Place sample probe in hole
  - Backfill with pea gravel to level of 0.6 meters from the surface
  - Seal around probe with bentonite
  - Equilibrate for 24 hours before sampling

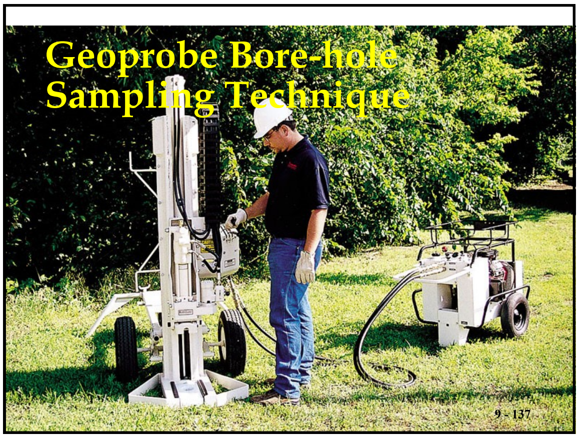
9 - 135

Sample Probe in the Ground



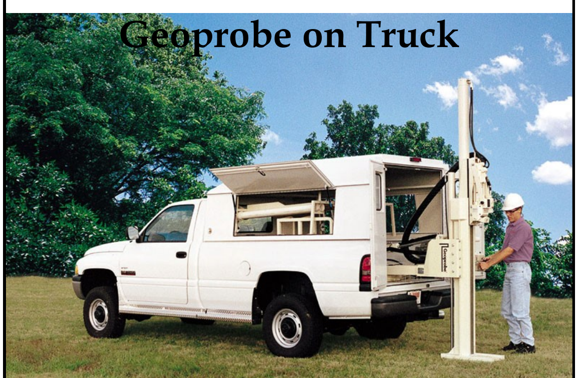
9 - 136

Geoprobe Bore-hole Sampling Technique



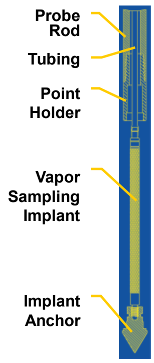
9 - 137

Geoprobe on Truck



9 - 138

Soil Gas Sampling



9 - 139

Sampling Procedure

- Sampling
  - Open the sampling valve and tank valve
  - Sample at a flow rate of 500 mL/min until sample tank gauge is zero
  - Disconnect from sampling system
  - Pressurize to 1,060 mm Hg with helium

9 - 140

Sampling Procedure

- Record final pressure (may also be pressurized in the laboratory)
- Landfill gas sample is acceptable if N_2 is < 20%

9 - 141

Federal Reference Method 25C Analysis

- FRM 25C: Oxidation, reduction and measurement of NMOC
- Initial NMOC analyzer performance test:
  - Oxidation catalyst efficiency check
  - Reduction catalyst efficiency check
  - Analyzer linearity check (not CO^2)

9 - 142

Federal Reference Method 25C Analysis

- NMO Analyzer daily calibration
- NMO response factor

9 - 143

NMOC Concentration

$$C_t = \frac{\frac{P_{tf}}{T_{tf}}}{\frac{P_t}{T_t} - \frac{P_{ti}}{T_{ti}}} * \frac{1}{((1 - B_w) - C_{N2})r} * \sum_{j=1}^{r} C_{tm(j)}$$

9 - 144

Weaknesses/Strengths of FRM 25/25A/25C/18 to LFG Monitoring

9 - 145

Advantages: FRM 25

- Measures only VOC (excludes Methane)
- Responds equally to all VOC

9 - 146

Disadvantages: FRM 25

- Potential positive bias that may vary according to source category
- Relatively poor precision

9 - 147

Advantages: FRM 25A

- Very good precision
- Real time analysis
- Relatively low detection limit

9 - 148

Disadvantages: FRM 25A

- Does not respond equally to all VOC
- Requires a separate measurement of Methane to convert THC to NMOC

9 - 149

Advantages: FRM 25C

- Measures only VOC (excludes Methane)
- Responds equally to all VOC
- No Condensation Trap (sample tupe won't plug)

9 - 150

Disadvantages: FRM 25C

- Potential positive bias that may vary according to source category
- Relatively poor precision
- No condensation trap (can miss VOC)

9 - 151

Advantages: FRM 18

- Good precision
- Low detection limits
- Can exclude methane

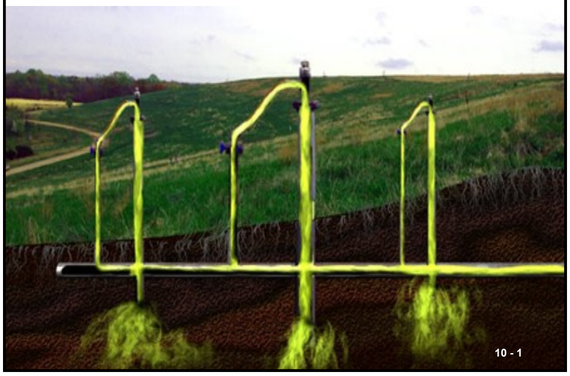
9 - 152

Disadvantages: FRM 18

- Measures individual organic compounds - not total VOC
- Requires calibration standards for all measured compounds

9 - 153

Landfill Gas (LFG) Collection System (GCCS)



10 - 1

Landfill Gas Collection System (GCCS)

- If the NMOC mass emission rate as calculated using the Tier 2 site-specific NMOC concentration is equal to or greater than 34 megagrams per year, the landfill owner or operator must either:
- (A) Submit a gas collection and control system design plan within 1 year as specified in §60.767(c) and install and operate a gas collection and control system within 30 months according to §60.762(b)(2)(ii) and (iii);
- Determine a site-specific methane generation rate constant and recalculate the NMOC emission rate using the site-specific methane generation rate using the Tier 3 procedures specified in paragraph (a)(4) of this section; or

10 -2

Landfill Gas Collection System (GCS) Review

- **Design Plan Requirements**
- Under §60.752(b)(2), landfill owners/operators subject to control requirements (i.e., those with a calculated NMOC emission rate 50 Mg/yr (34 for XXX) are given the option to:
- (a) submit a collection and control system plan conforming to the specifications

  provided in §60.759,(60.769) or
- (b) submit a collection and control plan for an alternative design.
- The design plan provisions of the rule were intended to provide flexibility and allow innovation.
- A wide variety of system designs are possible, such as vertical wells, combination horizontal and vertical collection systems, horizontal trenches, and passive systems. All plans will need to be reviewed by the implementing agency on a case-by-case basis to ensure that they meet the requirements of §60.752(b)(2)(ii). (60.762(b)(2)(ii))

10 -3

Landfill Gas Collection System (GCS) Review

- For active collection systems, the plan must demonstrate that the collection system will:
- (1) be designed to handle, over the intended use period of the gas control or treatment system equipment, the maximum expected gas flow rate from the entire landfill area that warrants control;
- (2) collect gas from each area, cell, or group of cells in the landfill in which the initial solid waste has been placed for a period of 5 years or more if active or 2 years or more if closed or at final grade;
- (3) collect gas at a sufficient extraction rate (a rate sufficient to maintain a negative pressure at all well heads in the collection system without causing air infiltration, including any well heads connected to the system as a result of expansion or excess surface emissions, for the life of the blower); and
- (4) be designed to minimize off-site migration of subsurface gas.

10 -4

Landfill Gas Collection System (GCS) Review

- GCS design is based on expected LFG generation and a reasonable estimate of how LFG can be collected to meet overall LFG collection and control objectives.
- The GCS wellfield design outlines the type, placement and spacing of collectors and the lateral and header piping network.
- Collectors can consist of vertical wells, horizontal wells, leachate management components, under cap collectors and other applicable devices.

10 -5

Landfill Gas Collection System Review

- The design should address the whole of the targeted disposal area, accommodate the maximum LFG generation rates expected over the life of the landfill and provide a degree of redundancy in the event of operational changes.
- GCS designs can vary greatly on a regional basis or even a site basis due to types of waste streams accepted, climate, operational goals and waste filling practices. The designer must take these parameters into account to develop an effective and regulatorily compliant GCS.

10 -6

Landfill Gas Collection System Review

- Existing Site Conditions: Site conditions and operational goals both influence the design of a GCS. Site conditions such as landfill geometry, moisture, compaction rates, waste types, waste depths, cover soils permeability and final cover all affect GCS design.
- Moisture: The greater the moisture within the waste mass, the faster LFG will be generated and the higher the peak LFG generation rate. A more rapid LFG generation rate also leads to a waste mass that tends to settle faster, which may cause damage to collectors that may need to be assessed and potentially replaced.

10 -7

Gas Collection and Control System Components

- Landfill Gas Collection Points
  - Vertical Wells
  - Caisson Wells
  - Horizontal collectors
  - Leachate cleanout risers
- Landfill Gas Collection Piping
  - Laterals
  - Header
- Condensate Management
  - Sumps
  - Driplegs
- Control System - Blower/Flare

10 -8

Landfill Gas Collection System Review

- Liquids: Liquids within the waste mass may decrease the pore space within the waste mass, decreasing the ability of LFG to move to the LFG extraction wells. Thus, landfills with higher moisture content may have a smaller effective radius (or zone) of influence for individual collectors and may require more collectors for the same area of coverage.
- Added Liquids: Conversely, some sites choose to add moisture to promote decomposition, which increases LFG generation but may increase GCS operational costs due to additional wells, increased settlement and larger header sizing.

10 -9

Landfill Gas Collection System Review

Other Factors Affecting the GCS :

- Physical properties of the waste mass such as waste density (compaction use).
- Addition of any gypsum wall board, onions and any material containing sulfur.
- Materials used for daily, intermediate and final cover also vary depending on local availability of soils, climate and approvals for alternate cover materials.
- The more impermeable the intermediate and final cover, the greater the potential well spacing and the better the LFG wells are likely to operate.

10 -10

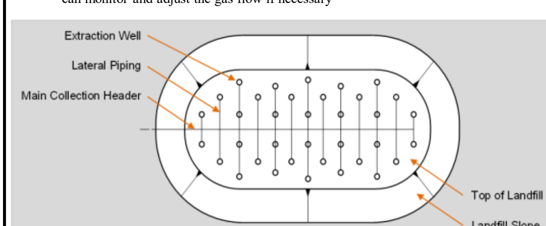
Landfill Gas Collection System Review

- **Climate:** The two most critical elements are temperature and the precipitation. Accounting for temperature involves considering how GCS components will respond both during typical and extreme weather events.
- For example, sites in areas that experience extended temperatures below ºC (32ºF) require freeze protection on equipment and vessels, and all header pipes and laterals should be buried to prevent freezing.
- Alternately, sites in very warm, sunny areas can have exposed GCS components experience significant thermal movement as they expand during the day and then contract overnight.
- Precipitation leads to additional liquids within the landfill. It enters the waste mass through the working face or via percolation through the various cover layers. Landfills in areas of high precipitation should limit liquids entering the landfill because it can affect LFG generation and/or operation of the GCS

10 -11

Landfill Gas Collection System Review

- **Gas Collection Systems:** Collection systems can be configured as vertical wells, horizontal trenches or a combination of both. Advantages and disadvantages of each type of well are listed in the following Table. Regardless of whether wells or trenches are used, ideally each wellhead is connected to lateral piping that transports the LFG to a main collection header, as illustrated in the Figure below. The collection system should be designed so that the operator can monitor and adjust the gas flow if necessary



10 -12

Landfill Gas Collection System Review

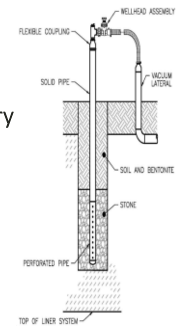
- Table of Advantages and Disadvantages of Vertical and Horizontal LFG Collection Wells Vertical Wells Horizontal Wells

Vertical Wells		Horizontal Wells	
Advantages	Disadvantages	Advantages	Disadvantages
▪ Minimal disruption of landfill operations if placed in closed area of landfill ▪ Most common design ▪ Reliable and accessible for inspection and pumping	▪ Increased operation and maintenance required if installed in active area of landfill ▪ Availability of appropriate equipment ▪ Delayed gas collection if installed after site or cell closes	▪ Facilitates earlier collection of LFG ▪ Reduced need for specialized construction equipment ▪ Allows extraction of gas from beneath an active tipping area on a deeper site	▪ Increased likelihood of air intrusion until sufficiently covered with waste ▪ More prone to failure because of flooding or landfill settlement

10 -13

Standard Vertical LFG Extraction Well

- Drilled on existing slopes, but located based on compliance and odors
- Perforated casing allows LFG entry
- Solid pipe and bentonite used to prevent air intrusion
- Wellhead controls vacuum application and LFG flow



10 -14

Standard Vertical LFG Extraction Well

Advantages

- Most Common
- Effective in Waste Thicknesses greater than 40 Feet
- Less Sensitive to Vertical Waste settlement
- Less Sensitive to Adverse Liquid impacts
- Pumps For Liquid Removal Can be added Easily

10 -15

Standard Vertical LFG Extraction Well

Disadvantages

- Difficult to Extend and Maintain beyond Original Installation Depth
- May Impact Ongoing Waste Placement Activities
- Subject To Damage By Workface equipment
- May Impact Closure/End-Use Activities
- Requires Specialty Contractor/
- Equipment to Install
- May Be Time Lag Between LFG generation and ability to Install Wells

10 -16

Vertical Extraction Wells Typical Design Parameters

- In-refuse wells are typically drilled to 75% of the refuse depth or until leachate is reached
- Boreholes are typically 24” to 36” diameter
- Typical 200 ft to 400 ft between in-refuse wells
- Casing is PVC, HDPE or carbon steel (infrequently)
- Perforated with slots, holes or screen. Typically perforated in bottom 1/3 to 2/3. Perforations normally start no closer than 20 ft from surface.

10 -17

Vertical Extraction Wells Versus Horizontal Collectors

- Can use either vertical wells or horizontal collectors while refuse is being placed. Horizontal collectors may cause less interference with refuse placement.
- Horizontal collectors must be installed as refuse is being placed. Cannot be installed “after the fact.” Exception is surface collectors
- Vertical wells generally produce better quality LFG (higher methane content) and allow greater operating flexibility
- Horizontal collectors may be more sensitive to damage from differential settlement and leachate flooding

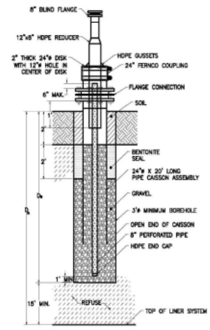
10 -18

Horizontal Collectors General Design Parameters

- Installed as refuse is being filled
- Typically spaced 100 to 200 ft horizontally and 40 to 60 ft vertically
- They consist of a pipe in a trench filled with porous material (e.g., crushed stone or tire chips)
- Pipe is typically HDPE with holes drilled within or coated CMP or PVC with alternating diameters (nested within each other)
- When used as a single layer just below the landfill surface, and under a membrane cover, they are sometimes called "surface collectors"

LFG Extraction Wells With Caisson

- Drilled on existing slopes (top down)
- Installed on cell floor (bottom up)
- Perforated casing allows LFG entry
- Caisson pipe and bentonite used to prevent air intrusion
- Wellhead controls vacuum application and LFG flow



10 -20

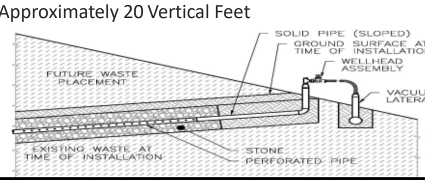
LFG Extraction Wells With Caisson

- Advantages not require re-drills
- Caisson protects well from damage
- ▪ Less Sensitive to Vertical
- Waste Settlement
- Pumps For Liquid Removal can be added Easily
- If installed on drainage
- layer (bottom up), does
- not require pumps, air and
- forcemain lines

10 -21

Horizontal Collectors

- Trench excavation on existing slopes or plateaus
- Perforated casing allows LFG entry
- Soil cover, solid pipe and bentonite used to prevent air intrusion
- Wellhead controls vacuum application and LFG flow
- Low-Permeability, On-Site Soil Backfill
- Do Not Operate Without Sufficient Cover – Approximately 20 Vertical Feet



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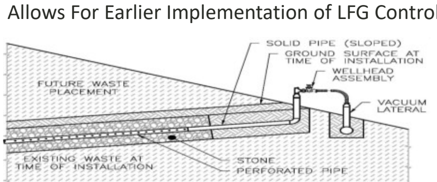
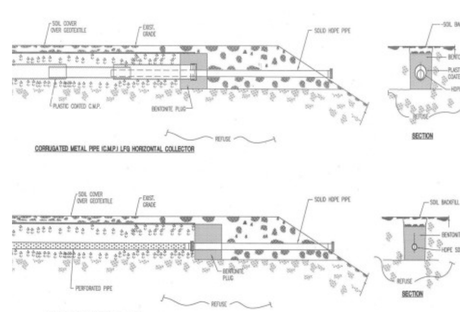
Horizontal Collectors

- Advantages
- Minimal Impact to Ongoing Operations
- Less Susceptible to Damage by Operations
- Does Not Require Specialty Equipment/Contractor
- Relatively Inexpensive to Construct
- Allows For Earlier Implementation of LFG Control

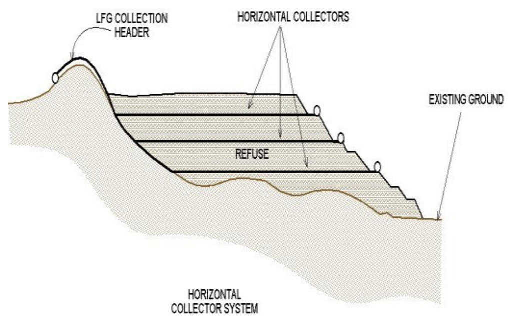


10 -23

Typical Horizontal Collector Arrangements



Typical Horizontal Collector Arrangement



Well Casing Material Design Considerations

Design Consideration	PVC Pipe	HDPE Pipe
Material Properties	Most suitable for vertical well casing construction due to its strength and temperature resistance. Differential settlement of the waste mass may lead to brittle fracture of the casing, allowing some degree of gas flow through the fracture.	Better suited for horizontal well casing and header and lateral pipe applications due to its flexibility and resistance to crushing. Often used in vertical wells since the piping will deform and bend with settlement. However, severe settlement may pinch the pipe and seal it off, inhibiting LFG flow.
	Material rigidity is susceptible to breaking by heavy equipment; however, field observations have also shown that broken PVC material can still act as a gas conduit.	Does not serve as a gas conduit when pinched.
	Resistant to pinching, elongation and deformation of perforations/slots; however, more vulnerable to ultraviolet radiation and brittleness from low temperatures.	Flexible and able to withstand the inherent shifting of a waste mass; due to the flexible properties of HDPE, perforations/slots are discouraged.
Installation	Fabricated as it is lowered into place; PVC sections, including extensions, are connected via threads or via slip couplings, screws and glue.	Fabricated prior to installation using specialized equipment and trained technicians to fuse sections together.
Temperature	Better suited for high gas temperatures <82˚C (180˚F).	Not recommended for long-term service above 60˚C (140˚F).
Cost	Price has remained relatively stable between 2013 and 2018.	Price fluctuates based on petroleum market rates. In 2018, approximately 25 percent higher cost than comparable PVC casing.

10 -27

Vertical Extraction Wells General Design Parameters

- In-refuse wells are typically drilled to 75% of the refuse depth or until leachate is reached
- Boreholes are typically 24” to 36” diameter
- Typical 200 ft to 400 ft between in-refuse wells
- Casing is PVC, HDPE or carbon steel (infrequently)
- Perforated with slots, holes or screen. Typically perforated in bottom 1/3 to 2/3. Perforations normally start no closer than 20 ft from surface.

10 -28

Vertical Extraction Wells Typical Design Parameters (Cont.)

- Deeper perforations increase a well’s radius of influence and reduce the potential for air infiltration.
- Wells can be equipped with leachate pumps
- In-soil wells can be used for migration control and sometimes groundwater NMOC migration. They can be equipped with groundwater pumps

10 -29

United States Environmental Protection Agency
Office of Air Quality Planning and Standards Research Triangle Park, NC 27711
EPA-453R/96-004 February 1999

Air

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Municipal Solid Waste Landfills, Volume 1:

Summary of the Requirements for the New Source Performance Standards and Emission Guidelines for Municipal Solid Waste Landfills

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Office of Air Quality Clean Air OAQPS Planning and Standards

10 -30

Summary of the Requirements for the New Source Performance Standards NSPS) and Emission Guidelines(EG) for Municipal Solid Waste Landfills - APPENDIX E Collection System Design Plans

- All owners and operators of affected landfills are required to submit to the Administrator a collection and control system design plan prepared by a professional engineer. This appendix provides a summary of the design plan requirements for all collection systems: active collection systems that meet the requirements of §60.759 (60.769 XXX) as well as alternate collection systems. It also provides guidance on what to look for in such plans and case study examples.

10 -31

Landfill Gas Collection System Review

Review of Plans:

- In reviewing design plans for active collection systems designed to meet §60.759 (60.769), it is important to ensure that adherence to each of the requirements in the section entitled "Specifications for Active Collection Systems" is adequately demonstrated.
- In reviewing alternate plans (for active or passive systems), it is important to ensure that the requirements listed in the "Design Plan Requirements" section are followed.
- It is also important to recognize that the rule includes operational standards along with monitoring and reporting requirements to ensure that landfill gas is extracted from the landfill at a sufficient rate.
- Section 60.753 (60.763) requires operation of collection systems so that the methane concentration is less than 500 ppmv at all points around the perimeter of the collection area and along a pattern that traverses the landfill at 30-meter intervals.
- The design plan must include a topographical map with the proposed monitoring route. This operational standard ensures that LFG is extracted at a sufficient rate and off-site migration is minimized. Any undetected flaws in the plan will most likely have to be corrected after the system is operating to meet the operational standards.

10 -32

- Sufficient discretion needs to be exercised to avoid the installation of inadequate collection systems. Failure to recognize an inadequate collection system design could lead to excessive periods of noncompliance or required replacement of the collection system.
- Such an occurrence would be detrimental to the environment and create an unnecessary financial burden on the landfill owner or operator.
- For this reason, an appropriate burden must be placed on the landfill owner/operator to demonstrate that the operational standards will be achievable with the proposed design.
- Such demonstrations should be supported by performance data at that landfill or a similar landfill when practical. At a minimum, the landfill owner/operator should be required to provide a written rational and appropriate engineering calculations for the design of systems which do not adhere to the requirements in §60.759.

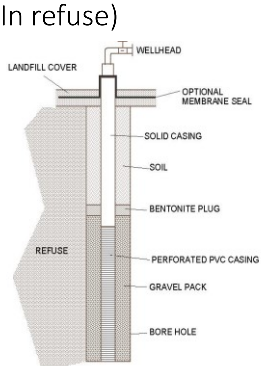
10 -33

Well Siting:

- Site active vertical collection wells such that the radius of influence (ROI) from a collection well includes all gas-producing areas of the landfill that contain solid waste.
- The ROI is the radial distance that a well can effectively extract LFG through compacted refuse without causing air infiltration.
- A well extracts LFG from compacted refuse by creating a negative pressure drop in the surrounding refuse. The negative pressure drop is produced by maintaining a negative gauge pressure within a well using blowers or air compressors. The pressure drop at a location in the landfill decreases as the distance from the collection well increases.
- The ROI for a collection well is defined as the shortest distance radially out from a collection well to where the pressure drop gradient applied by the blower or compressor approaches zero.

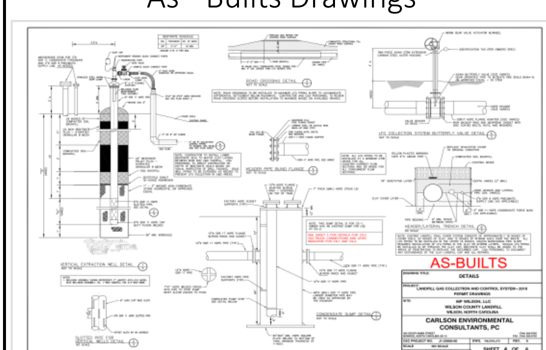
10 -34

Typical Single Completion LFG Well (In refuse)



- Well bore seal prevents direct air infiltration along casing
- Gravel pack enhances LFG extraction and reduces screen pluggage
- Wellhead incorporates:
  - Flow control valve
  - Pressure taps
  - Flow monitoring device (optional)
  - Thermometer opening

As - Builts Drawings



10 -36

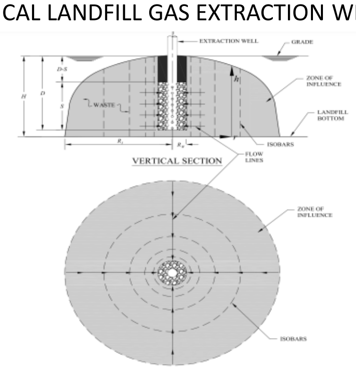
Extraction Wellhead

Well Region of Influence (ROI)

- The interior ROI and perimeter ROI used to determine well placement will be determined using one of the following: use a single ROI of 30 meters for siting both perimeter and interior wells; or & Establish a site-specific ROI by following the procedure in EPA Method 2E. (Method 2E data may already be available if LFG flow rate was tested to perform Tier 3 NMOC emission rate calculations.)

10 -38

VERTICAL LANDFILL GAS EXTRACTION WELLS

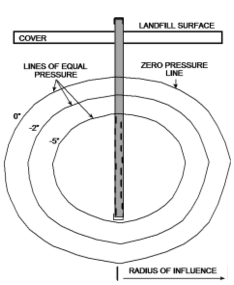


10 -39

- The ROI will be used to site wells along the perimeter of all gas-producing areas of the landfill, at a maximum of one ROI from the perimeter boundary.
- After siting the perimeter wells, the interior wells will be sited. Both perimeter and interior wells will be spaced no more than two times the ROI apart. (Well spacing greater than this value will create gaps between the ROI of adjacent wells.
- The wells would be unable to collect LFG from these gaps.) Wells will be staggered such that all gas-producing areas of the landfill containing solid waste that has been in the landfill for at least 5 years (for active sites) or 2 years (for sites at closure or final grade) are covered by the ROI.

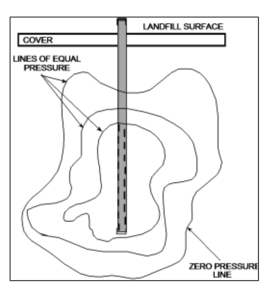
10 -40

Theoretical Zone of Influence of a Landfill Gas Well



- Increases in the vacuum at the wellhead will extend the zone of capture and increase LFG flow at that well
- Influence is assumed to be greater horizontally than vertically
- Variations in vacuum are the operator's only control tool

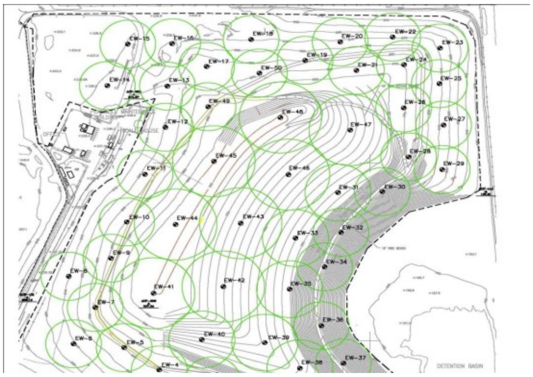
Actual Zone of Influence of a Landfill Gas Extraction Well



A well's "zone of capture" is most likely will not be ideal due to:

- Variations in waste characteristics
- Interim cover and cell configuration
- Presence of liquids

LFG System Radius of Influences



Landfill Gas Collection System (GCS) Review Reference Materials

- **Municipal Solid Waste Landfill Gas Design Course APTI Workshop 018**
- Municipal Solid Waste Landfills, Volume 1: Summary of Requirements for New Source Performance Standards and Emission Guidelines Appendix E
- Landfill Off-gas Collection and Treatment Systems

  Engineers Manual: US Army Corps of Engineers

  Engineering and Design

10 -44

Municipal Solid Waste Landfill Gas Design Plan Review

Student Manual

APTI Workshop T018

First Edition

Prepared for

North Carolina State University
Industrial Extension Service
Environmental Programs

Prepared by

EMCON
N9558 Millhome Lane
Kiel, Wisconsin 53042
(920) 894-4088

Industrial Extension Service | College of Engineering | North Carolina State University

10 -45

Example ROI Calculation Sheet

COMPUTATION SHEET

PROJECT TITLE: Site A Landfill PROJECT NO: 86685-001.000
DESCRIPTION: Radius of Influence CALC NO: SHEET 1 OF 6
PREP. BY: SDA DATE: 3/10/97 CHKD BY: DATE: 3/97

REFERENCE

Required: Estimate the theoretical radius of influence (ROI) for the three test landfill gas (LFG) extraction wells at the Site A Landfill using both EMCON and NSPS methods.

Method: The following methods were used to estimate the theoretical ROI for a LFG extraction well.

A). EMCON Method (from *Methane Generation and Recovery from Landfills*, EMCON, 1982, pg. 81)

$$Q_w = \frac{k \pi R^2 t D r}{C}$$

where:
- Q_w = individual extraction well LFG flow rate [L/s]
- k = conversion factor (1.157×10^{-8}) [(L/s)/(mL/day)]
- R = radius of influence [m]
- t = refuse thickness [m]
- D = in-place refuse density [kg/m^3]
- r = methane production rate [mL/kg/day]
- C = fractional methane concentration [-]

1. Noting that the methane production rate (r) divided by the fractional methane concentration (C) is equal to the LFG production rate (G), and solving for the ROI yields:

$$R = \left(\frac{Q_w}{k \pi t D G}\right)^{1/2}$$

2. Converting from metric to english units yields the following conversion factors (allowing input in english units):

Q_w (from cfm to L/s):

$$\frac{1\ ft^3}{min} \times \frac{1\ min}{60\ sec} \times \frac{28.317\ L}{ft^3} = 0.47195$$

t (from ft to m):

EMCON

United States Environmental Protection Agency | Office of Air Quality Planning and Standards Research Triangle Park, NC 27711 | EPA-453R/96-004 February 1999

Air

EPA Municipal Solid Waste Landfills, Volume 1:

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APPENDIX E

COLLECTION SYSTEM DESIGN PLANS

OAQPS

10 -47

Municipal Solid Waste Landfills, Volume 1: Summary of Requirements for New Source Performance Standards and Emission Guidelines | Stationary Sources of Air Pollution | US EPA

EM 1110-1-4016
30 May 2008

US Army Corps of Engineers

ENGINEERING AND DESIGN

LANDFILL OFF-GAS COLLECTION AND TREATMENT SYSTEMS

ENGINEER MANUAL

10 -48


0120-685-52-01

NSPS LANDFILL GAS COLLECTION AND CONTROL SYSTEM DESIGN PLAN AND MONITORING PLAN

OTTAWA COUNTY FARMS LANDFILL

COOPERSVILLE, MICHIGAN

Prepared in Accordance with 40 CFR 60 Subpart WWW

May 2016

PREPARED BY
Weaver Consultants Group

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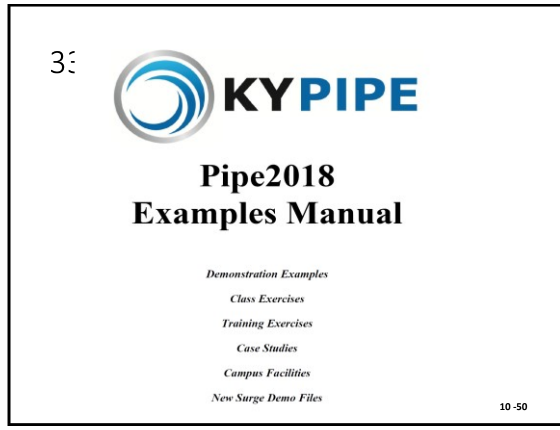

KYPIPE

Pipe2018
Examples Manual

Demonstration Examples
Class Exercises
Training Exercises
Case Studies
Campus Facilities
New Surge Demo Files

10 -50

US EPA Office of Research and Development

CLEAN AIR TECHNOLOGY CENTER

EPA

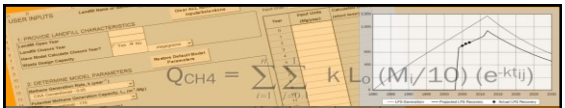
LandGEM

Landfill Gas Emissions Model

Version 3.03

U.S. Environmental Protection Agency
Office of Research and Development
Center for Emergency Solutions and Environmental Response (CESER)
and
Clean Air Technology Center (CATC)
Research Triangle Park, North Carolina

June 2020



Landfill Gas Modeling

- Landfill gas (LFG) modeling is the practice of forecasting gas generation and recovery based on past and future waste disposal histories and estimates of gas collection system (GCS) efficiency.
- It is an important step in the project development process because it provides an estimate of the amount of recoverable LFG that will be generated over time.

7 - 2

- EPA's Greenhouse Gas Reporting Program (GHGRP) has a separate set of modeling equations and parameters to estimate methane emissions for annual reporting purposes.
- For regulatory applications, the modeler must use the specific procedures, default values and test methods prescribed in the rule.

7 - 3

LFG Constituents

- Major gases
  Methane (CH_4)
  Carbon Dioxide (CO_2)
- Trace gases - Hydrogen
- Moisture

7 - 4

Actual Gas Composition

- **Methane (CH_4) 45 to 58 %**
- **Carbon Dioxide (CO_2) 35 to 45 %**
- **Oxygen (O_2) >1 to 5 %**
- **Nitrogen (N_2) >1 to 5 %**
- **Hydrogen (H_2) >1 to 5 %**
- **Water Vapor (H20) >1 to 5 %**
- **Trace Organics >1 to 3 %**

7 - 5

Factors Influencing Gas Generation

- **Refuse quantity**
- **Refuse composition**
- **Refuse compaction**
- **Refuse age**
- **Moisture content !!!**
- **Liquid addition / bioreactors**
- **pH and alkalinity**
- **Nutrients**
- **Toxics**
- **Temperature**

7 - 6

Modeling biological decomposition
How much gas will a given volume of trash generate as it decomposes?
Methane Yield Potential (Lo)
1.4 to 7.0 cu ft / lb (LFG @50% methane) Average Landfill: 4.5 cu ft / lb (**LFG @ 50%** methane)
AP-42: 100 cm methane /Mg – 3.2 cu ft/ lb (LFG @50% methane)

7 - 7

How quickly will it be generated?

First Order Decay Rate Constant (k)
– How much gas a given volume of trash will generate per year
– Range: 0.07 to 0.27 cu ft / lb / yr
– Average: 0.15 cu ft / lb / yr

7 - 8

Gas Generation

- Landfill Gas (LFG)– What Is It? Gaseous by-product of decomposition of organic materials in sanitary landfills under anaerobic conditions

7 - 9

Why Gas Generation Curves Are Needed

- Regulatory drivers
- Gas system design
- Gas system evaluations
- Beneficial use projects
- Performing due diligence evaluations of potential or actual project performance

7 - 10

Regulatory Requirements for Gas Generation Curves

- Tier I estimates
- Tier II estimates
- Tier III estimates

7 - 11

The NESHAP rule applies to area source landfills if they have a design capacity equal to or greater than 2.5 million Mg or 2.5 million m^3 and have estimated uncontrolled emissions of 50 (34) Mg/yr NMOC or more or if they are operated as a bioreactor.

7 - 12

The new EG/NSPS require landfills that meet the design capacity (> than 2.5 million megagrams design capacity) criteria to periodically calculate uncontrolled annual NMOC emissions. If an area source landfill that currently has estimated uncontrolled emissions less than (34) and increases to 34 Mg/yr (50 MG/yr for closed facilities) in the future, it will become subject to the Subpart OOO at that time.

7 - 13

Contaminants of Potential Concern Commonly Found in LFG are:

1,1,1-Trichloroethane (Methyl Chloroform) 1,1,2,2- Tetrachloroethene
1,1-Dichloroethane (ethylidene dichloride) 1,1-Dichloroethene (vinylidene chloride) 1,2-Dichloroethane (ethylene dichloride) 1,2-Dichloropropane (propylene dichloride)
Acetone Acrylonitrile Benzene Bromodichloromethane
Carbon disulfide Carbon tetrachloride
Chlorobenzene Chloroethane
Chlorofluorocarbons Chloroform
Chloromethane Dichlorobenzene
Dichloromethane (Methylene Chloride) Hexane
Hydrogen sulfide Methyl ethyl ketone
Methyl isobutyl ketone Methyl mercaptans
Tetrachloroethylene (perchloroethylene) Toluene
Trichloroethylene Vinyl chloride
Xylenes

7 - 14

Estimating Uncontrolled Landfill Gas Emissions

- **To estimate uncontrolled emissions of the various constituents present in LFG, total LFG emissions must first be estimated. Un-controlled CH4 emissions are estimated with a theoretical first-order kinetic model of CH4 production. This model is known as the Landfill Gas Emissions Model (LandGEM).**
- **A version of LandGEM for the personal computer (PC) can be downloaded from EPA's website at:**
- Clean Air Technology Center Products | Clean Air Technology Center | US EPA
- **A user's manual is also available on this website**

The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas, methane, carbon dioxide, non-methane organic compounds, and individual air pollutants from municipal solid waste landfills.

7 - 16

LandGEM can be used to estimate mass emissions of NMOCs to assess applicability of a site with regards to the NSPS and EG. The model can also be used to estimate mass emissions of the COPCs by using either default or user-specified LFG concentration data.

7 - 17

LandGEM can use either site-specific data to estimate emissions or default parameters if no site-specific data are available. The model contains two sets of default parameters, CAA defaults and inventory defaults. The CAA defaults are based on federal regulations for MSW landfills laid out by the Clean Air Act (CAA) and can be used for determining whether a landfill is subject to the control requirements of these regulations.

7 - 18

CAA Defaults—The CAA defaults are based on requirements for MSW landfills laid out by the Clean Air Act (CAA), including the NSPS/EG and NESHAP. This set of default parameters yields conservative emission estimates and can be used for determining whether a landfill is subject to the control requirements of the NSPS/EG or NESHAP.

7 - 19

LandGEM is considered a screening tool—the better the input data, the better the estimates.
Often, there are limitations with the available data regarding waste quantity and composition, variation in design and operating practices over time, and changes occurring over time that impact the emissions potential.

7 - 20

INTRO - Contains an overview of the model and important notes about using LandGEM

USER INPUTS
Allows users to provide landfill characteristics, determine model parameters, select up to four gases or pollutants (total landfill gas, methane, carbon dioxide, NMOCs, and 46 air pollutants), and enter waste acceptance rates

7 - 21

POLLUTANTS - Allows users to edit air pollutant concentrations and molecular weights for existing pollutants and add up to 10 new pollutants

INPUT REVIEW - Allows users to review and print model inputs

7 - 22

METHANE - Calculates methane emission estimates using the first-order decomposition rate equation

7 - 23

RESULTS - Shows tabular emission estimates for up to four gases/pollutants (selected in the USER INPUTS worksheet) in megagrams per year, cubic meters per year, and user’s choice of a third unit of measure (average cubic feet per minute, cubic feet per year, or short tons per year)

7 - 24

GRAPHS - Shows graphical emission estimates for up to four gases/ pollutants (selected in the USER INPUTS worksheet) in megagrams per year, cubic meters per year, and user's choice of a third unit of measure (selected in the RESULTS worksheet)

7 - 25

INVENTORY - Displays tabular emission estimates for all gases/pollutants for a single year specified by users

REPORT - Allows users to review and print model inputs and outputs in a summary report

7 - 26

LandGEM uses the following first-order decomposition rate equation to estimate annual emissions over a time period that you specify. The model parameters *k* and *Lo* used by this decomposition equation are described further in Section 3.0 of the LandGEM users manual.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}}$$

7 - 27

Where:
Q_{CH4} = annual methane generation in the year of the calculation (m3/year)
i = 1 year time increment
n = (year of the calculation) - (initial year of waste acceptance)
j = 0.1 year time increment
***k* = methane generation rate (year-1)**
***Lo* = potential methane generation capacity (m3/Mg)**
Mi = mass of waste accepted in the ith year (Mg)
t_{ij} = age of the jth section of waste mass Mi accepted in the ith year (decimal years, e.g., 3.2 years)

7 - 28

Methane Generation Rate (*k*)
The *Methane Generation Rate*, *k*, determines the rate of methane generation for the mass of waste in the landfill. The higher the value of *k*, the faster the methane generation rate increases and then decays over time.

7 - 29

The value of *k* is primarily a function of four factors:
- **Moisture content of the waste mass,**
- **Availability of the nutrients for microorganisms that break down the waste to form methane and carbon dioxide,**
- **pH of the waste mass, and**
- **Temperature of the waste mass.**

7 - 30

Use EPA Method 2E to determine site-specific *k* values for user-specified data. The *k* value, as it is used in the first-order decomposition rate equation, is in units of 1/year, or year-1.

7 - 31

Site-specific landfill information is generally available for the variables *Mi*, *c*, and *t*. When refuse acceptance rate information is scant or unknown, *Mi* can be determined by dividing the mass of refuse in-place by the age of the landfill. The average annual acceptance rate should only be estimated by this method when there is inadequate information available on the actual average acceptance rate.

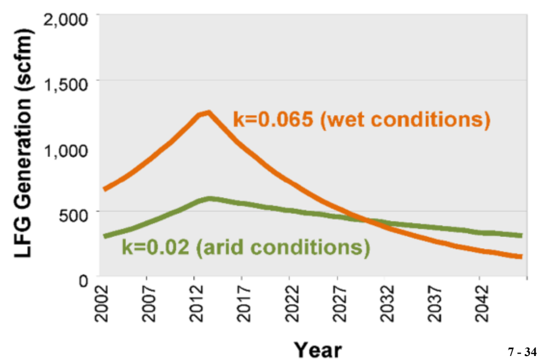
7 - 32

Values for the Methane Generation Rate (*k*).

Default Type	Landfill Type	*k* Value year $^{-1}$
CAA	Conventional	0.05 (default)
CAA	Arid Area	0.02
Inventory	Conventional	0.04
Inventory	Arid Area	0.02
Inventory	Wet (Bioreactor)	0.7

7 - 33

LFG Generation Variance by k Value



7 - 34

Potential Methane Generation Capacity (*Lo*)

The *Potential Methane Generation Capacity*, *Lo*, depends only on the type and composition of waste placed in the landfill. The higher the cellulose content of the waste, the higher the value of *Lo*.

7 - 35

The default *Lo* values used by LandGEM are representative of MSW. The *Lo* value, as it is used in the first-order decomposition rate equation, is measured in metric units of cubic meters per megagram to be consistent with the CAA.

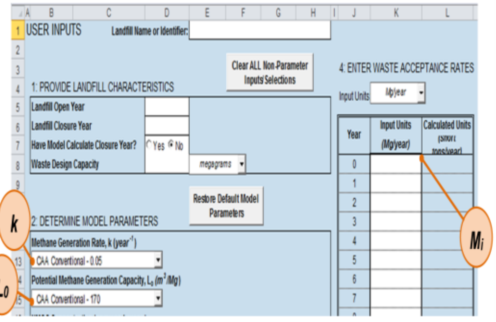
7 - 36

Values for the Potential Methane Generation Capacity (*Lo*)

Emission Type	Landfill Type *Lo*	Value - m³/Mg
CAA (default)	Conventional	170
CAA	Arid Area	170
Inventory	Conventional	100
Inventory	Arid Area	100
Inventory	Wet (Bioreactor)	96

7 - 37

LandGEM User Inputs Worksheet



7 - 38

Uncontrolled Landfill Gas Constituents

Compound	VOC[a]	Hazardous Air Pollutant[b] (HAP)
1,1,1-Trichloroethane (methyl chloroform)	N	Y
1,1,2,2-Tetrachloroethane	Y	Y
1,1-Dichloroethane (ethylidene dichloride)	Y	Y
1,1-Dichloroethene (vinylidene chloride)	Y	Y
1,2-Dichloroethane (ethylene dichoride)	N	Y
1,2-Dichloropropane (propylene dichloride)	Y	Y
2-Propanol (isopropyl alcohol)	Y	N
Acetone	N	N
Acrylonitrile	Y	Y
Bromodichloromethane	Y	N
Butane	Y	Y
Carbon disulfide	Y	Y
Carbon monoxide[c]	N	N
Carbon tetrachloride	Y	Y
Carbonyl sulfide	Y	Y
Chlorobenzene	Y	Y
Chlorodifluoromethane	N	N
Chloroethane (ethyl chloride)	Y	Y
Chloroform	Y	Y
Chloromethane	Y	N

7 - 39

(Continued)

Compound	VOC[a]	Hazardous Air Pollutant[b] (HAP)
Dichlorobenzene[d]	Y	Y
Dichlorodifluoromethane	N	N
Dichlorofluoromethane	N	N
Dichloromethane (methylene chloride)	N	Y
Dimethyl sulfide (methyl sulfide)	Y	N
Ethane	N	N
Ethanol	Y	N
Ethyl mercaptan (ethanethiol)	Y	N
Ethylbenzene	Y	Y
Ethylene dibromide	Y	Y
Fluorotrichloromethane	N	N
Hexane	Y	Y
Hydrogen sulfide	N	N
Mercury[e]	N	Y
Methyl ethyl ketone	Y	Y
Methyl isobutyl ketone	Y	Y
Methyl mercaptan	Y	N
Pentane	Y	N
Perchloroethylene (tetrachloroethylene)	N	Y
Propane	Y	N

7 - 40

(Continued)

Compound	VOC[a]	Hazardous Air Pollutant[b] (HAP)
Trichloroethylene (trichloroethene)	Y	N
t-1,2-Dichloroethene	Y	N
Vinyl chloride	Y	Y
Xylenes	Y	Y

NOTE: This is not an all-inclusive list of potential LFG constituents, only those for which test data were available at multiple sites (EPA 1995).
[a] Reactive VOC.
[b] Hazardous Air Pollutants listed in Title III of the 1990 Clean Air Amendments.
[c] Carbon monoxide is not a typical constituent of LFG, but does exist in instances involving landfill (underground) combustion. Of 18 sites where CO was measured, only 2 showed detectable levels of CO.
[d] Source tests did not indicate whether this compound was the para-or ortho- isomer. The para- isomer is a Title III-listed HAP.
[e] No data were available to speciate total Hg into the elemental and organic forms.

7 - 41

Gas/Pollutant Default Data Used in LandGEM

Gas/Pollutant	Concentration (*ppmv*)	Molecular Weight	Notes
Gases			
Total landfill gas	Not applicable	30.03	
Methane	Not applicable	16.04	
Carbon dioxide	Not applicable	44.01	
NMOCs	4,000 for CAA 600 for Inventory No or Unknown Co-disposal 2,400 for Inventory Co-disposal	86.18	
Pollutants:			
1,1,1-Trichloroethane (methyl chloroform)	0.48	133.41	A
1,1,2,2-Tetrachloroethane	1.1	167.85	A, B
1,1-Dichloroethane (ethylidene dichloride)	2.4	98.97	A, B
1,1-Dichloroethene (vinylidene chloride)	0.20	96.94	A, B
1,2-Dichloroethane (ethylene dichloride)	0.41	98.96	A, B
1,2-Dichloropropane (propylene dichloride)	0.18	112.99	A, B
2-Propanol (isopropyl alcohol)	50	60.11	B
Acetone	7.0	58.08	
Acrylonitrile	6.3	53.06	A, B
Benzene	1.9 for No or Unknown Co-disposal 11 for Co-disposal	78.11	A, B
Bromodichloromethane	3.1	163.83	B
Butane	5.0	58.12	B
Carbon disulfide	0.58	76.13	A, B
Carbon monoxide	140	28.01	

7 - 42

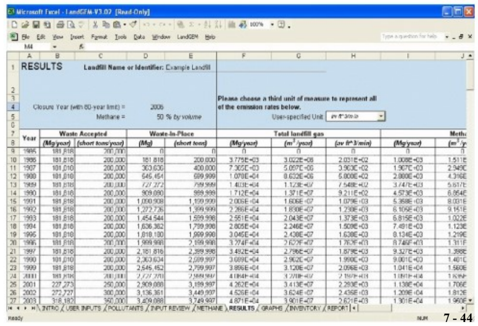
Gas/Pollutant Default Data Used in LandGEM (cont.)

Carbon tetrachloride	4.0×10^{-3}	153.84	A, B
Carbonyl sulfide	0.49	60.07	A, B
Chlorobenzene	0.25	112.56	A, B
Chlorodifluoromethane	1.3	86.47	
Chloroethane (ethyl chloride)	1.3	64.52	A, B
Chloroform	0.03	119.39	A, B
Chloromethane	1.2	50.49	B
Dichlorobenzene	0.21	147	B, C
Dichlorodifluoromethane	16	120.91	
Dichlorofluoromethane	2.6	102.92	B
Dichloromethane (methylene chloride)	14	84.94	A
Dimethyl sulfide (methyl sulfide)	7.8	62.13	B
Ethane	890	30.07	
Ethanol	27	46.08	B
Ethyl mercaptan (ethanethiol)	2.3	62.13	B
Ethylbenzene	4.6	106.16	A, B
Ethylene dibromide	1.0×10^{-3}	187.88	A, B
Fluorotrichloromethane	0.76	137.38	B
Hexane	6.6	86.18	A, B
Hydrogen sulfide	36	34.08	
Mercury (total)	2.9×10^{-4}	200.61	A
Methyl ethyl ketone	7.1	72.11	A, B
Methyl isobutyl ketone	1.9	100.16	A, B
Methyl mercaptan	2.5	48.11	B
Pentane	3.3	72.15	B
Perchloroethylene (tetrachloroethylene)	3.7	165.83	A
Propane	11	44.09	B
t-1,2-Dichloroethene	2.8	96.94	B
Toluene	39 for No or Unknown Co-disposal 170 for Co-disposal	92.13	A, B
Trichloroethylene (trichloroethene)	2.8	131.40	A, B
Vinyl chloride	7.3	62.50	A, B
Xylenes	12	106.16	A, B

A. Hazardous air pollutants (HAP) listed in Title III of the 1990 Clean Air Act Amendments.
B. Considered volatile organic compounds (VOC), as defined by U.S. EPA in 40 CFR 51.100(s).
C. Source tests did not indicate whether this compound was the para- or ortho- isomer. The para- isomer is a Title III-listed HAP.

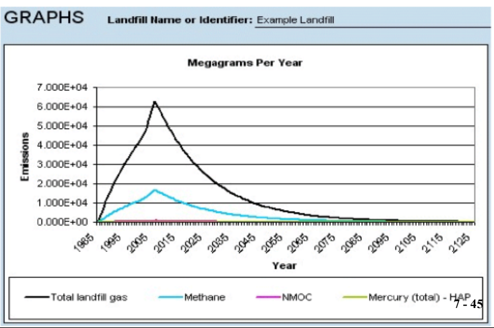
7 - 43

Results of LandGEM Worksheets



7 - 44

Graphical Results in Units of Megagrams per Year



7 - 45

The U.S. EPA has provided default values for model input parameters; however, the values are based on data obtained from conventional landfills. Waste stabilization can be enhanced and accelerated so as to occur significantly more rapidly if the landfill is designed and operated as a bioreactor, primarily involving moisture addition.

7 - 46

Enhanced waste stabilization will result in increased gas pro-duction; therefore, the values of the first- order model parameters k (the landfill gas generation rate constant) and L_0 (the methane generation potential) will be different from conventional landfills. The objective of this report is to investigate landfill gas collection from wet cells and estimate first-order gas generation model parameters.

7 - 47

EPA United States Environmental Protection Agency

EPA-600/R-05/072
June 2005

First-Order Kinetic Gas Generation Model Parameters for Wet Landfills

www.epa.gov/nrmrl/pubs/600r05072/600r05072.pdf

Mathematical Models for Methane Generation

- *Zero-Order Model (SWANA 1998)*
- *First-Order Model (SWANA 1998)*
- *Modified First –Order Model*
- *Multiphase Model*
- *Second Order Model*
- *Scholl Canyon Model*
- *Triangular Model*
- *Palos Verdes Model*
- *Sheldon Arleta Model*
- *GASFILL Model*

http://www.nrel.gov/docs/legosti/fy97/26041.pdf

FINAL REPORT

COMPARISON OF MODELS FOR PREDICTING
LANDFILL METHANE RECOVERY

Prepared for:

THE SOLID WASTE ASSOCIATION OF NORTH AMERICA
1100 Wayne Avenue
Suite 700
Silver Spring, Maryland 20910

Prepared By:

SCS ENGINEERS
11260 Roger Bacon Drive
Reston, Virginia 22090
(703) 471-6150

In Association With:

Mr. Donald Augenstein
Institute for Environmental Management
4277 Pomona Avenue
Palo Alto, California 94306
(415) 856-2850

March 1997
File No. 0295028

Example Model Problem with LandGEM

Model Parameters
==
=
Lo : 100.00 m^3 / Mg
k : 0.0400 1/yr
NMOC : 595.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume
Air Pollutant : Vinyl Chloride (HAP/VOC)
Molecular Wt = 62.50 Concentration = 7.340000 ppmV
==
=
Landfill Parameters
==
=
Landfill type : Co-Disposal
Year Opened : 1969 Current Year : 1999 Closure Year: 1980
Capacity : 792000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Example Model Problem with LandGEM

Model Parameters
==
=
Lo : 100.00 m^3 / Mg
k : 0.0400 1/yr
NMOC : 595.00 ppmv
Methane : 50.0000 % volume
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Air Pollutant : Vinyl Chloride (HAP/VOC)
Molecular Wt = 62.50 Concentration = 7.340000 ppmV
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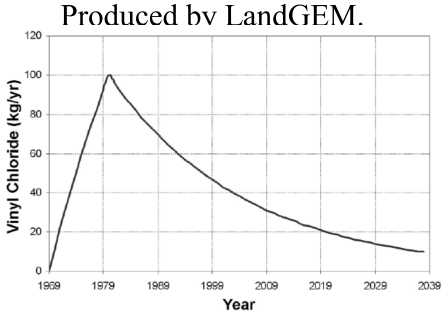
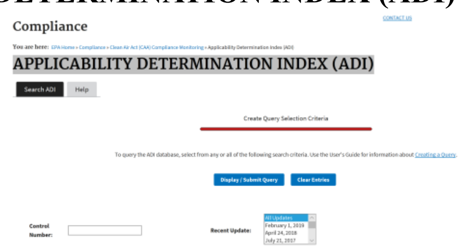
=
Landfill Parameters
==
=
Landfill type : Co-Disposal
Year Opened : 1969 Current Year : 1999 Closure Year: 1980
Capacity : 792000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Example COPC Emission Estimates Produced by LandGEM.

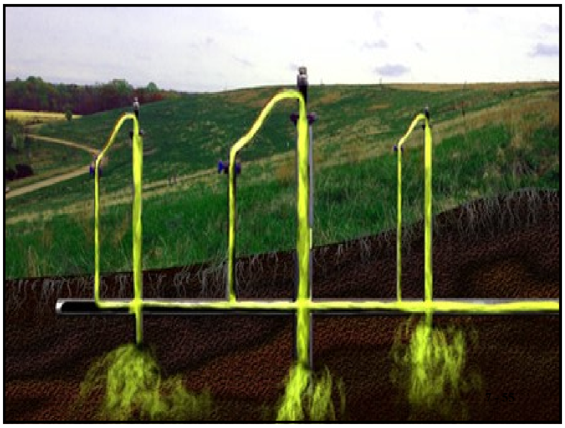


APPLICABILITY DETERMINATION INDEX (ADI)

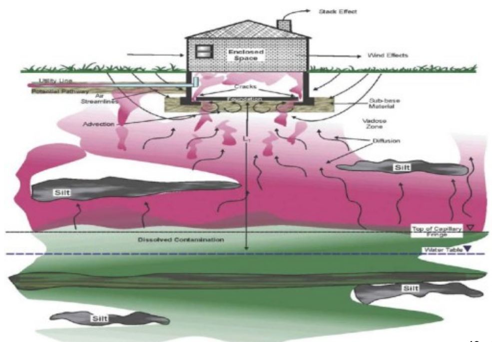


https://cfpub.epa.gov/adi/index.cfm?CFID=1402866&CFTOKEN=65162593&jsessionid=063091e1f1ffcbdd138643704a706078635eTR&requesttimeout=180

7 - 54



Vapor Intrusion



12 - 1

Vapor Intrusion

- **Vapor intrusion is the migration of** volatile chemicals from the subsurface into overlying buildings (USEPA 2002). Volatile chemicals may include volatile organic compounds, select semi-volatile organic compounds, and some inorganic analytes, such as elemental mercury and hydrogen sulfide. Methane should be considered where it is appropriate

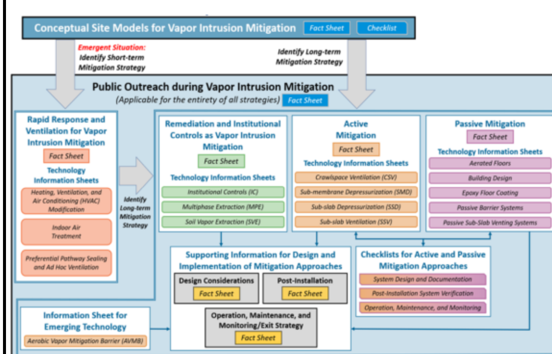
12 - 2

Federal RCRA Subtitle D Monitoring Requirements

Methane Concentration Standards	
At property Line	< 100 % of the Lower Explosive Limit (LEL) 5 % by volume
In On-site structures	< 25 % of the Lower Explosive Limit (LEL) 1.25 % by volume
Condensate	Not permitted to be returned to landfill without composite liners

12 - 3

Interactive Directory of Vapor Intrusion Mitigation Training



vim (itrcweb.org)

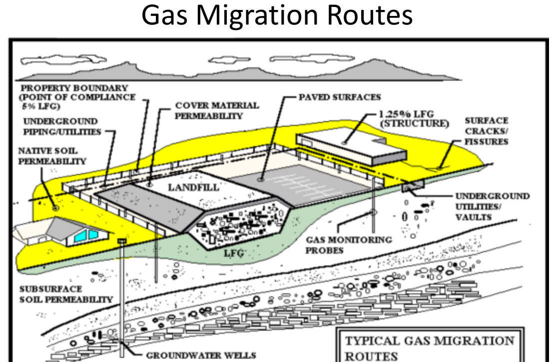
12 - 4

How Far Can Landfill Gas Travel?

- It is difficult to predict the distance that landfill gas will travel because so many factors affect its ability to migrate underground; however, travel distances greater than 1,500 feet have been observed. Computer models that use data about the landfill and surrounding soil conditions can predict the approximate migration patterns from existing landfills.
- A study conducted by the New York State Department of Health found that of 38 landfills, gas migrated underground up to 1,000 feet at 1 landfill, 500 feet at 4 landfills, and only 250 feet from the landfill boundary at 33 landfills. — (ATSDR 1998)

12 - 5

Diagram Depicting Potential Landfill Gas Migration Routes



12 - 6

What is Vapor Intrusion?

Vapor Intrusion is the migration of chemicals from a spill through soil into indoor air

Not drinking contaminated groundwater…..but you may be breathing vapors from contaminated groundwater

12 - 7

EPA United States Environmental Protection Agency

OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)

November 2002

EPA530-D-02-004

12 - 8

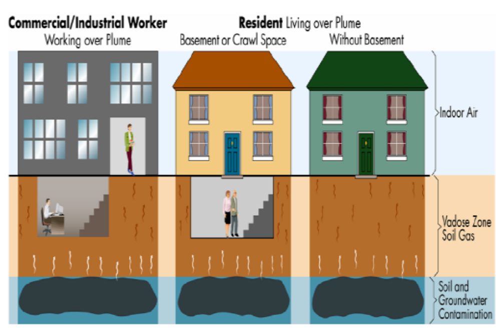
OSWER Publication 9200.2-154

OSWER TECHNICAL GUIDE FOR ASSESSING AND MITIGATING THE VAPOR INTRUSION PATHWAY FROM SUBSURFACE VAPOR SOURCES TO INDOOR AIR

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
June 2015

12 - 9

Vapor Intrusion



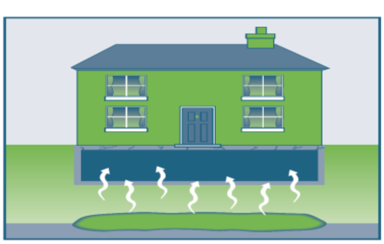
Typical conceptual model of vapor intrusion
(Interstate Technology & Regulatory Council (ITRC)

12 - 10

ITRC

Technical and Regulatory Guidance

Vapor Intrusion Pathway: A Practical Guideline



January 2007

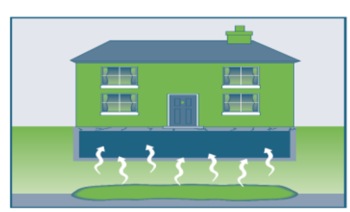
12 - 11

ITRC

Technical and Regulatory Guidance Supplement

Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios

A Supplement to Vapor Intrusion Pathway: A Practical Guideline



January 2007

Prepared by
The Interstate Technology & Regulatory Council
Vapor Intrusion Team

12 - 12

ITRC Website

ITRC offers Guidance Documents and Internet based training classes on a wide variety of remediation tools and approaches

Visit www.itrcweb.org for details.

12 - 13

General framework for evaluating vapor intrusion

- **Implementation of a community outreach program that provides timely information to concerned citizens and property owners**
- **Use of a phased approach that allows for the collection and use of both generic and site specific information/data**
- **Development of an accurate conceptual site model (CSM) that is representative of site conditions to assist with the investigative strategy and ensure proper use of the data**
- **Application of an iterative process (i.e., starts with available data and collects additional data only to meet the needs of making informed decisions)**

12 - 14

General framework for evaluating vapor intrusion (cont.)

- **Allowance for a site-specific evaluation using modeling, soil gas sampling, indoor air sampling, or mitigation at any point in the process**
- **Evaluation of multiple lines of evidence that result in decisions based on professional judgment**
- **Consideration of current and future site use**
- **Use of screening levels based on the appropriate exposure scenario (e.g., residential, nonresidential, occupational) consistent with the regulatory agency**

12 - 15

Soil Gas Sampling

- Active methods
  - Through driven/drilled rods
  - Extraction of soil gas
- Passive methods
  - Burial of adsorbent
  - Diffusion of soil gas
- Considerations
  - Purge and sample volumes
  - Flow rate, vacuum, and leak tests
  - Sample containers
  - Temporal effects
  - Real-time sample and analysis
  - Sample density and locations
  - Hydrophobic adsorbents

12 - 16

Sub-slab Soil Gas Sampling

- Soil gas most likely to enter structure
  - May detect chemicals originating within building
- Collect indoor air concurrently for comparison
- Sample at slab base and/or at depth
- Permanent or temporary sample points
- Active and passive approaches
- Near slab soil gas may be alternative

Active sampling

Passive sampler insertion

12 - 17

Indoor Air Sampling

- Generally performed after subsurface sampling
- Pre-sampling building survey
  - Appendix G
- Focus on contaminants of concern (COCs)
- Length of sampling time
- Analytical methods
- Active and passive methods
- Locations
  - Crawlspace samples
  - Ambient samples

Examples of sampling canisters (shown with sporting equipment to illustrate size)

12 - 18

Vapor Intrusion Scenarios

Vapor Intrusion Pathway:

1. Gas station in residential neighborhood
2. Drycleaner in strip mall located adjacent to neighborhood
3. Large industrial facility with long plume under several hundred buildings
4. Vacant lot with proposed Brownfield development over groundwater plume
5. Vacant large commercial building with warehouse space and office space
6. Apartment building with parking garage over groundwater plume
7. Landfill gas migration into nearby residential or commercial buildings

12 - 19

Scenario: Site Description

- Scenario 3
- Groundwater
  - 15-30 feet bgs
  - Chlorinated compounds
  - Plume - miles long
- Lithology
  - Alluvial soil
  - Clay layer 3-5 feet bgs
- Hundreds of structures
  - Basements, crawlspaces, slabs
- Groundwater "hot spot" concentrations 100x screening levels
- Similar to Redfield site

Solvent contamination and adjoining mixed-use neighborhood

12 - 20

Mallard Lake Landfill LFG Migration Hanover Park, IL - EPA Region V Web Site

Site Profile - Mallard Lake Landfill - EPA OSC Response

12 - 21

Continuous Monitoring of Structures for Landfill Gas Intrusion

Publication Summary CalRecycle

12 - 22

Vapor Intrusion Resources & Links

http://www.itrcweb.org/vaporintrusion/

Performing Landfill Gas Investigations (ca.gov)

http://www.dtsc.ca.gov/AssessingRisk/upload/HERD_POL_Eval_Subsurface_Vapor_Intrusion_interim_final.pdf

12 - 23

Kansas Vapor Intrusion Guidance

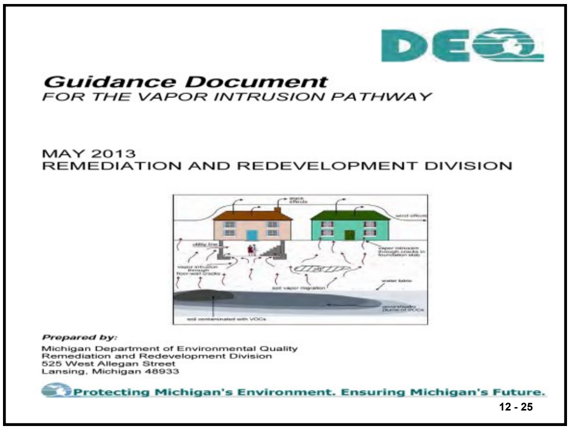
Kansas Department of Health and Environment
Environmental Remediation

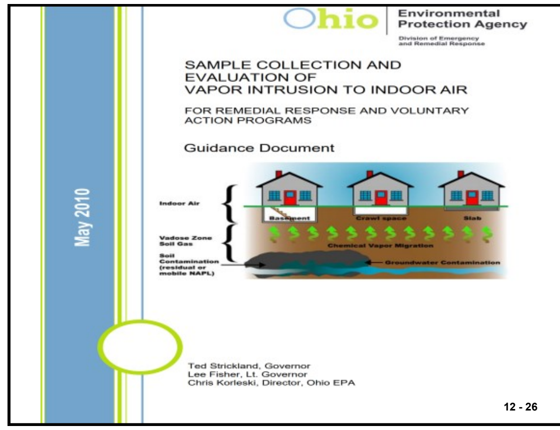
August 2016

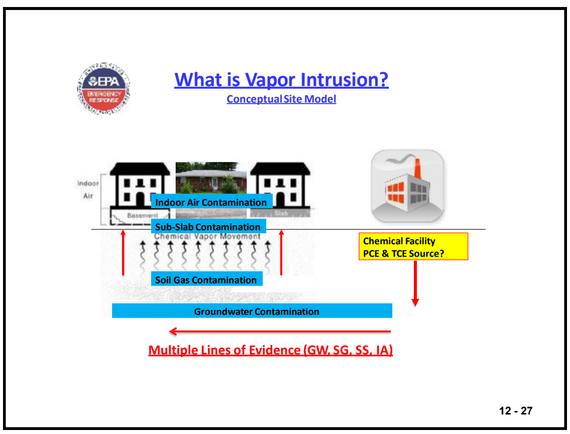
Kansas Department of Health and Environment
Division of Environment
Bureau of Environmental Remediation
Curtis State Office Building
1000 SW Jackson, Suite 410
Topeka, KS 66612-1367

Ks_VI_Guidance.pdf

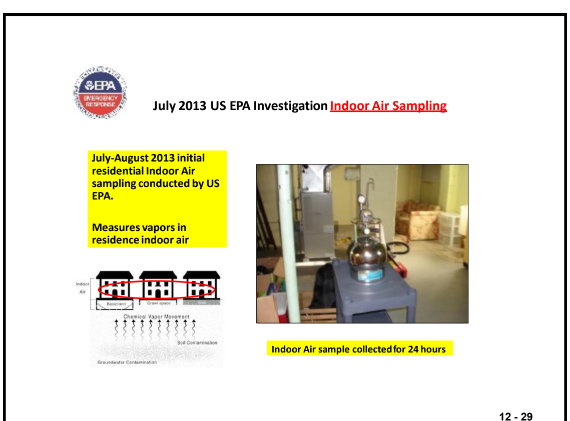
12 - 24

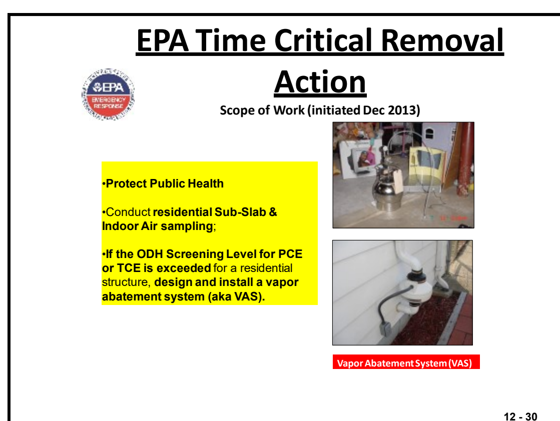

DEQ
Guidance Document
FOR THE VAPOR INTRUSION PATHWAY
MAY 2013
REMEDIATION AND REDEVELOPMENT DIVISION
Prepared by:
Michigan Department of Environmental Quality
Remediation and Redevelopment Division
525 West Allegan Street
Lansing, Michigan 48933
Protecting Michigan's Environment. Ensuring Michigan's Future.
12 - 25


Ohio Environmental Protection Agency
Division of Emergency and Remedial Response
May 2010
SAMPLE COLLECTION AND EVALUATION OF VAPOR INTRUSION TO INDOOR AIR
FOR REMEDIAL RESPONSE AND VOLUNTARY ACTION PROGRAMS
Guidance Document
Indoor Air
Basement
Crawl space
Slab
Vadose Zone Soil Gas
Chemical Vapor Migration
Soil Contamination (residual or mobile NAPL)
Groundwater Contamination
Ted Strickland, Governor
Lee Fisher, Lt. Governor
Chris Korleski, Director, Ohio EPA
12 - 26

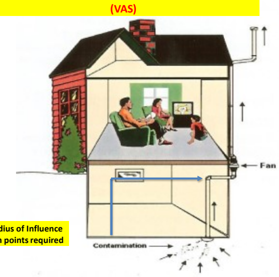

What is Vapor Intrusion?
Conceptual Site Model
Indoor Air
Indoor Air Contamination
Basement
Sub-Slab Contamination
Chemical Vapor Movement
Soil Gas Contamination
Groundwater Contamination
Chemical Facility
PCE & TCE Source?
Multiple Lines of Evidence (GW, SG, SS, IA)
12 - 27


July 2013 US EPA Investigation
Sub-Slab Sampling
July-August 2013 initial Sub-Slab sampling conducted by US EPA.
Measures vapors below residence basement/slab.
Sub-Slab sample collected for 24 hours
12 - 28


July 2013 US EPA Investigation Indoor Air Sampling
July-August 2013 initial residential Indoor Air sampling conducted by US EPA.
Measures vapors in residence indoor air
Indoor Air sample collected for 24 hours
12 - 29


EPA Time Critical Removal Action
Scope of Work (initiated Dec 2013)
•Protect Public Health
•Conduct residential Sub-Slab & Indoor Air sampling;
•If the ODH Screening Level for PCE or TCE is exceeded for a residential structure, design and install a vapor abatement system (aka VAS).
Vapor Abatement System (VAS)
12 - 30

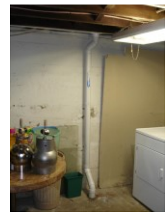
Vapor Abatement System
(VAS)



Overlapping Radius of Influence
1 to 2 extraction points required

12 - 31

Vapor Abatement System Installation
Extraction Pipe into Basement Floor



1 to 2 extraction points will be installed

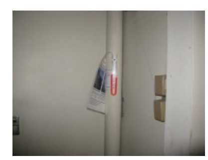
12 - 32

Vapor Abatement System Installation
Crawl Space

Crawl space installation.
PVC pipe installed under plastic liner

12 - 33

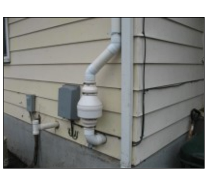
Vapor Abatement System Installation
Vacuum Reading – U Tube Manometer



Manometer reads 1-2" vacuum

12 - 34

Vapor Abatement System Installation
Outside Fan and Vent

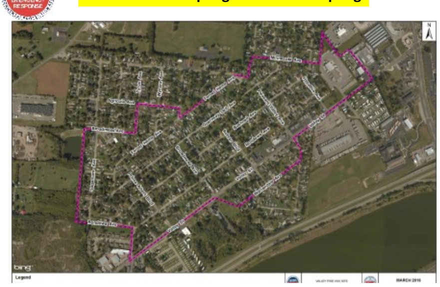


System Installation = 1-2 days

Follow-up proficiency air sampling @ 30 days

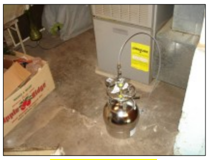
12 - 35

March 2016 Sampling Area – VI Sampling

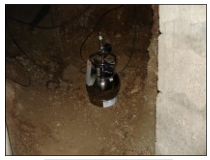


12 - 36

Properties Sampled to Date



Sub-Slab Sample

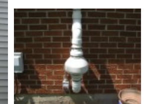


Crawl Space Sample

EPA has sampled a total of 417 residential properties. 573 properties in Area of Concern. Approx 40 denied access or vacant

12 - 37

Vapor Abatement System (VAS) Installations

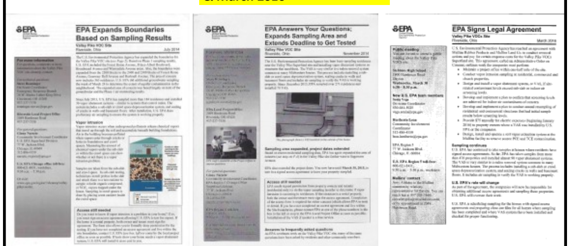


EPA has installed VAS at 89 of 92 residential properties eligible to receive a vapor abatement system.
2 residences = vacant
1 residence = deferred VAS until 2016

12 - 38

EPA Fact Sheets

Fact Sheets in July & Nov 2014 & March 2016



12 - 39

EPA Region 5 Web Site

www.epa.gov/oh/valley-pike-vocs

12 - 40

Vapor Intrusion (VI) Investigation Using the TAGA Mobile Laboratories

CLU-IN Webinar
29 August 2018

12 - 41

12 - 42

TAGA MOBILE LABORATORY

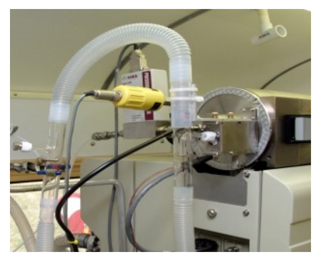
12 - 43



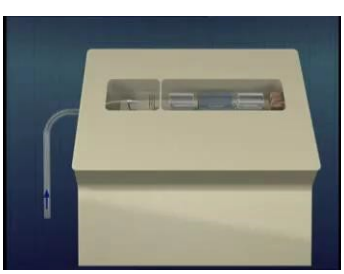
TAGA MOBILE LABORATORY

12 - 44

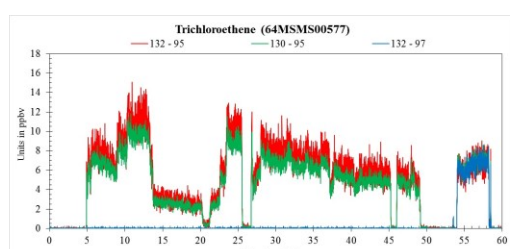
12 - 45



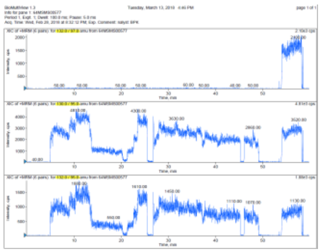
12 - 46



12 - 47



12 - 48



12 - 49

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Driver and Passenger Seating with Monitors

Cook County's Mobile Laboratory 1970's

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VAPOR INTRUSION

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Comparison Between Water And Air Contamination

WATER

Basis: 2 liters/day
Assume: TCE concentration is 5 ppb or 5 micrograms/liter (µg/L)
Daily impact: 2 L/day * 5 µg/L = 10 µg/day

AIR

Basis: 20 cubic meters/day
Assume: TCE concentration is 1 ppbv or 5.4 micrograms/cubic meter (µg/m³) Daily impact: 20 m³/day * 5.4 µg/m³ = 108 µg/day

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Lines of Evidence:

- Groundwater spatial (and vertical profiling, if appropriate) data with modeling
- Potable groundwater analysis
- Soil gas spatial concentrations (and vertical profiling, if appropriate), including subslab, with vertical profiling
- Ambient, crawlspace, and inside air concentrations and source determinations
- Building construction and conditions
- Constituent ratios

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Groundwater Spatial (and Vertical Profiling, if Appropriate) Data With Modeling

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Soil Gas Spatial Concentrations (and Vertical Profiling, if Appropriate), Including Subslab, with Vertical Profiling

Sorbent Tubes

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Ambient, Crawlspace, and Inside Air Concentration and Source's Determinations

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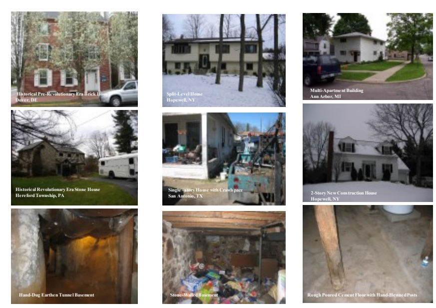
Building Construction And Conditions



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NC – Region 4
Region 5
Army Corps of Engineers Raritan Center Site, Edison, NJ – Region2
Berkley Products Site, Akron, PA – Region 3 Brewster Site , Brewster, NY – Region 2
Brick Township Landfill, Ocean City, NJ – Region 2 Brook Indsutries Bound Brook, NJ – Region 2
Butz Landfill Site, Jackson, PA – Region 3
Carter Carburetor Site, St. Louis , MO – Region 7 Charlevoix Groundwater Site, Charlevoix, MI – Region 5 Chemical Leaman Site, Gloucester, NJ – Region 2
Chillum Site, Chillum, MD – Region 3
Coldwell Trucking Site, Essex City, NJ – Region 2 Conell Dublier Site, South Plainfield, NJ – Region 2 Corry Site, Corry, PA – Region 3
Crossley Farm Site, Hereford Township, PA – Region 3 Crown Cleaners Site, Carthage, NY – Region 2 Delforge Site, Grand Prairie, TX – Region 6
Delmar Water Supply Well Site, Dalmar, DE - Region 3 Diaz Site, Holley, NY – Region 2
Dover Gas Light Site, Dover, DE - Region 3
Facet Enterprise Site, Elmira Heights, NY – Region 2 Federal Creosote Site, Manville, NJ – Region 2
Former Kelly Air Force Base, San Antonio, TX – Region 6
Former Manufactured Gas Plant Site, West Palm Beach, FL – Region 4 Fulton Site, Garden City, NY - Region 2
Garden State Cleaners Site, Buena Borough, NJ – Region 2 Grenada Manufacturing Site, Grenada, MS - Region 4 Georgia Street Site, Washington DC - Region 3
Glendive Site, Glendive, MT – Region 8
Grand Rapids VI ER, Grand Rapids, MI - Region 5
Grand Traverse Overall Supply Site, Traverse City, MI – Region 5 Grants Site, Grants NM – Region 6
Henry's Dry Cleaners Site, Laconia, NH – Region 1 Hidden Lane Landfill, Sterling, VA - Region 3
Higgins Disposal Site, Franklin Township, NJ – Region 2
Highway 71/72 – Region 6
Hopewell Precision Site, Hopewell Junction, NY – Region 2 Kaufman and Minteer Site, Jobstown, NJ – Region 2 Kentucky Avenue Site, Horseheads, NY – Region 2 Laureldale Groundwater Site – Grants Pass, OR – Region 10
Lawrence Aviation Site, Port Jefferson, NY – Region 2
Lehigh Valley Railroad Derailment Site, LeRoy, NY – Region 2 Liberty Industrial Finishings Site, Oyster Bay, NY – Region 2 Lillis Drive Site, Cuhahoga, Falls, OH - Region 5
Little Valley Site, Little Valley, NY – Region 2
Mackenzie Chemical Works, Suffolk County, NY – Region 2 Macon Naval Ordnance Plant, Macon, GA - Region 4 Mansfield Dump Site, Byram Township, NJ – Region 2 Marathon Battery Site, Putman City, NY – Region 2 Mattiace Site, Glen Cove, NY – Region 2
Mayfield Road Site - Mayfield Heights, OH - Region 5 McGaffey and Main Site, Roswell, NM – Region 6 MEW Site, Mountain View, CA – Region 9
Mills Gap Road Site, Skyland, NC - Region 4 Mitral Site, Harwinton, CT – Region 1 Moffett Field, Moffett, CA – Region 9 Mohonk Site – High Falls, NY – Region 2
Motorola 52nd Street Site, Phoenix, AZ – Region 9 Mueller Copper Tubing Site, Wynne, AR- Region 6 Murray Laundry Site, Salt Lake City, UT – Region 8
Nebraska Former Ordnance Plant Site, Mead, NE – Region 7 Olean Cleaners, Olean, NY – Region 2
Parker Solvent Site, Little Rock, AR – Region 6 Passyunk Soil Gas Site, Philadelphia, PA – Region 3 Peninsula Blvd Site, Hewlett, NY – Region 2 Perkasie Site, Perkasie, PA – Region 3
Pohatcong Site, Franklin Township, NJ – Region 2 Port Washington Site, North Hemstead, NY – Region 2 Radiation Technologies Site, Rockaway, NJ – Region 2 Railroad TCE, Warminster, PA - Region 3
Raritan Arsenal, Edison, NJ – Region 2 Raymark Site, Stratford, CT – Region 1 Rittenhouse Road, Norristown, PA - Region 3
Rockaway Boro Site, Rockaway Township, NJ – Region 2 San Gabriel Valley Site, Eouth El Monte, CA - Region 9 Scientific Chemical Processing Site, Carlstadt, NJ – Region 2 Scovill Schrader Site, Dickson, TN - Region 4
Shenandoah Road Site, East Fishkill, NY – Region 2 Sherwin Williams, Gibbsboro, NJ - Region 2
South Jersey Clothing Site. Buena Borough, NJ – Region 2 St. Louis Park Site, St. Louis Park, MN - Region 5 Sugarhouse VI PCE Site, Salt Lake City, UT - Region 8 Tranguch Site, Hazleton, PA – Region 3
Trex Properties Site, Charlotte, NC - Region 4 Trex Site, Grand Rapids, MI - Region 5
USMC Camp Lejeune, Jacksonville, NC – Region 4 Valmont Site, Hazleton, PA – Region 3
Vestal Site, Vestal, NY -Region 2
White Swan Site, Wall Township, NJ – Region 2

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TAGA Monitoring

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TAGA Monitoring with the Teflon Tube Using the Low Pressure Chemical Ionization (LPCI) Source

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Vapor Intrusion Discussion Points

Impacts Due to Vapor Intrusion
Impacts Due to Household Material Impacts
Impacts Due to Adjacent Building
Impacts Due to Adjoining Buildings
Impacts Due to Contaminated Potable Well Water
Impacts Due to Crawlspace Concentrations
Impacts Due to Presence in Contaminated Water in Sumps
Impacts Due to Same Source - Constituent Ratios
Impacts Due to Self-Polluting Operations
Impacts Due to Accidental/Intentional Releases
Impacts Due to Releases at Distances
Impacts Due to Groundwater Becoming Surface Water Impacts Due to Groundwater Being Used for Irrigation
Impacts Due to Sub-slab Contamination

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US EPA Vapor Intrusion Website

Vapor Intrusion | US EPA

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Guidance for Evaluating Landfill Gas Emissions from Closed or Abandoned Facilities and Examples

13 - 1

EPA United States Environmental Protection Agency

EPA-600/R-05/123a September 2005

GUIDANCE FOR EVALUATING LANDFILL GAS EMISSIONS FROM CLOSED OR ABANDONED FACILITIES

epa-600-r-05-123.pdf (clu-in.org)

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US EPA Guidance Manual Outline

- Chapter 1: Introduction
- Chapter 2: Landfill Gas Basics
- Chapter 3 Landfill Safety and Health Issues
- Chapter 4: Monitoring of Landfill Gases
- Chapter 5: Landfill Gas Control Measures
- Chapter 6: Communications

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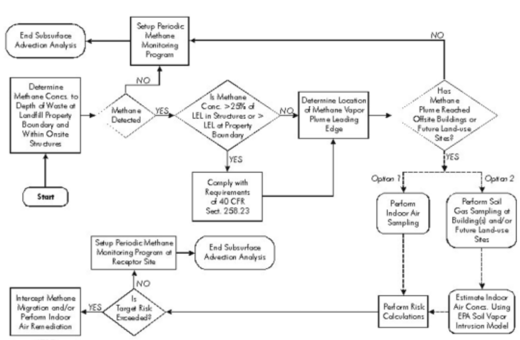
Landfill Gas Primer - An Overview for Environmental Health Professionals

- Appendices:

- Appendix A: Acronyms
- Appendix B: ASTDR Guidelines
- Appendix C: Health Studies
- Appendix D: Wright-Patterson Air Force Base- A Case Study
- Appendix E: Examples
- ATSDR - Landfill Gas Primer - An Overview for Environmental Health Professionals (cdc.gov)

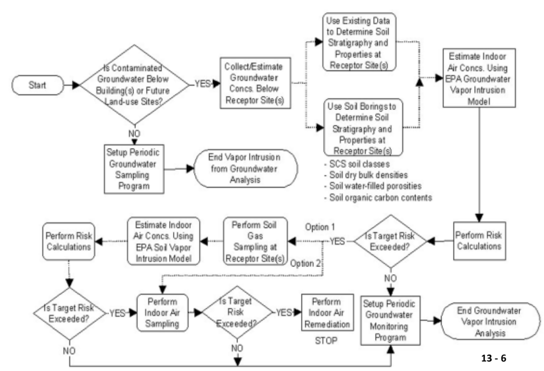
13 - 4

Flow Chart for Assessing Subsurface Vapor Migration by Convection.

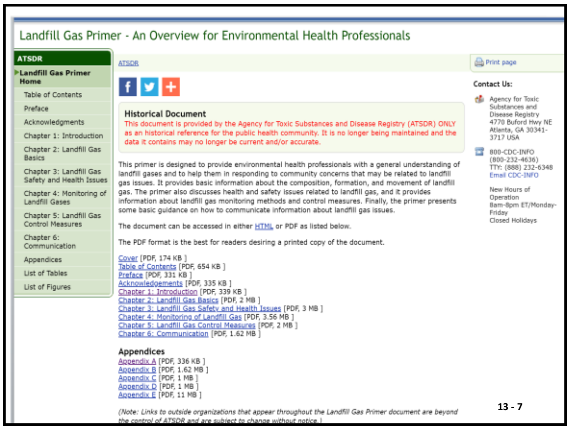


13 - 5

Flow Chart for Assessing Vapor Intrusion from Contaminated Groundwater



13 - 6


Landfill Gas Primer - An Overview for Environmental Health Professionals
ATSDR
Landfill Gas Primer Home
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Chapter 4: Monitoring of Landfill Gases
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Chapter 6: Communication
Appendices
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List of Figures
ATSDR
Print page
Historical Document
This document is provided by the Agency for Toxic Substances and Disease Registry (ATSDR) ONLY as an historical reference for the public health community. It is no longer being maintained and the data it contains may no longer be current and/or accurate.
This primer is designed to provide environmental health professionals with a general understanding of landfill gases and to help them in responding to community concerns that may be related to landfill gas issues. It provides basic information about the composition, formation, and movement of landfill gas. The primer also discusses health and safety issues related to landfill gas, and it provides information about landfill gas monitoring methods and control measures. Finally, the primer presents some basic guidance on how to communicate information about landfill gas issues.
The document can be accessed in either HTML or PDF as listed below.
The PDF format is the best for readers desiring a printed copy of the document.
Cover [PDF, 174 KB]
Table of Contents [PDF, 654 KB]
Preface [PDF, 331 KB]
Acknowledgements [PDF, 335 KB]
Chapter 1: Introduction [PDF, 339 KB]
Chapter 2: Landfill Gas Basics [PDF, 2 MB]
Chapter 3: Landfill Gas Safety and Health Issues [PDF, 3 MB]
Chapter 4: Monitoring of Landfill Gas [PDF, 3.56 MB]
Chapter 5: Landfill Gas Control Measures [PDF, 2 MB]
Chapter 6: Communication [PDF, 1.62 MB]
Appendices
Appendix A [PDF, 336 KB]
Appendix B [PDF, 1.62 MB]
Appendix C [PDF, 1 MB]
Appendix D [PDF, 1 MB]
Appendix E [PDF, 11 MB]
(Note: Links to outside organizations that appear throughout the Landfill Gas Primer document are beyond the control of ATSDR and are subject to change without notice.)
Contact Us:
Agency for Toxic Substances and Disease Registry
4770 Buford Hwy NE
Atlanta, GA 30341-3717 USA
800-CDC-INFO
(800-232-4636)
TTY: (888) 232-6348
Email CDC-INFO
New Hours of Operation
8am-8pm ET/Monday-Friday
Closed Holidays
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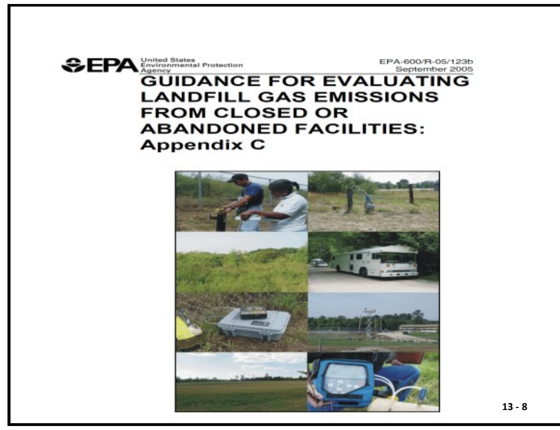
EPA United States Environmental Protection Agency
EPA-600/R-05/123b
September 2005
GUIDANCE FOR EVALUATING LANDFILL GAS EMISSIONS FROM CLOSED OR ABANDONED FACILITIES:
Appendix C
13 - 8


EPA United States Environmental Protection Agency
EPA-600/R-05/143
October 2005
A CASE STUDY DEMONSTRATING U.S. EPA GUIDANCE FOR EVALUATING LANDFILL GAS EMISSIONS FROM CLOSED OR ABANDONED FACILITIES
BUSH VALLEY LANDFILL
HARFORD COUNTY, MARYLAND
U.S.E.P.A. SUPERFUND PROJECT
DANGER
OLD LANDFILL
NO TRESPASSING
HAZARDOUS SUBSTANCE PRESENT
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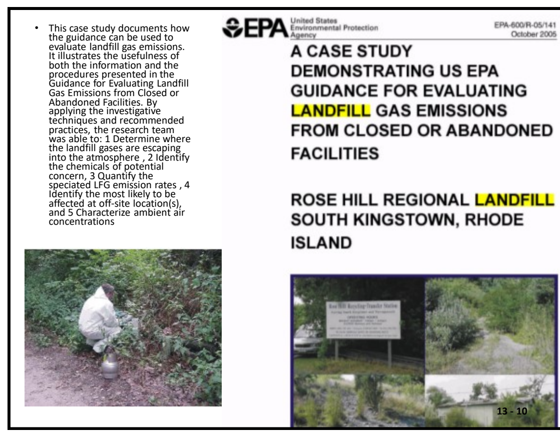
• This case study documents how the guidance can be used to evaluate landfill gas emissions. It illustrates the usefulness of both the information and the procedures presented in the Guidance for Evaluating Landfill Gas Emissions from Closed or Abandoned Facilities. By applying the investigative techniques and recommended practices, the research team was able to: 1 Determine where the landfill gases are escaping into the atmosphere , 2 Identify the chemicals of potential concern, 3 Quantify the speciated LFG emission rates , 4 Identify the most likely to be affected at off-site location(s), and 5 Characterize ambient air concentrations
EPA United States Environmental Protection Agency
EPA-600/R-05/141
October 2005
A CASE STUDY DEMONSTRATING US EPA GUIDANCE FOR EVALUATING LANDFILL GAS EMISSIONS FROM CLOSED OR ABANDONED FACILITIES
ROSE HILL REGIONAL LANDFILL
SOUTH KINGSTOWN, RHODE ISLAND
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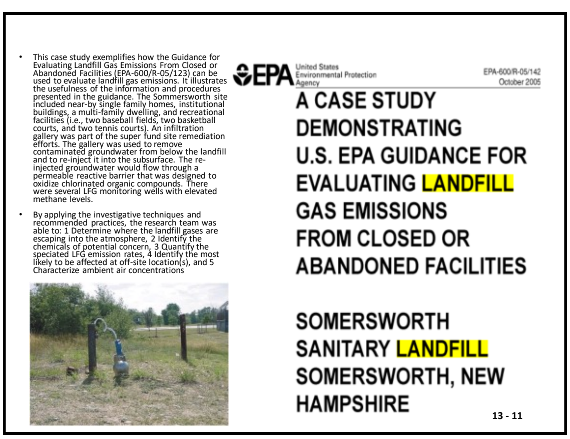
• This case study exemplifies how the Guidance for Evaluating Landfill Gas Emissions From Closed or Abandoned Facilities (EPA-600/R-05/123) can be used to evaluate landfill gas emissions. It illustrates the usefulness of the information and procedures presented in the guidance. The Sommersworth site included near-by single family homes, institutional buildings, a multi-family dwelling, and recreational facilities (i.e., two baseball fields, two basketball courts, and two tennis courts). An infiltration gallery was part of the super fund site remediation efforts. The gallery was used to remove contaminated groundwater from below the landfill and to re-inject it into the subsurface. The re-injected groundwater would flow through a permeable reactive barrier that was designed to oxidize chlorinated organic compounds. There were several LFG monitoring wells with elevated methane levels.
• By applying the investigative techniques and recommended practices, the research team was able to: 1 Determine where the landfill gases are escaping into the atmosphere, 2 Identify the chemicals of potential concern, 3 Quantify the speciated LFG emission rates, 4 Identify the most likely to be affected at off-site location(s), and 5 Characterize ambient air concentrations
EPA United States Environmental Protection Agency
EPA-600/R-05/142
October 2005
A CASE STUDY DEMONSTRATING U.S. EPA GUIDANCE FOR EVALUATING LANDFILL GAS EMISSIONS FROM CLOSED OR ABANDONED FACILITIES
SOMERSWORTH SANITARY LANDFILL
SOMERSWORTH, NEW HAMPSHIRE
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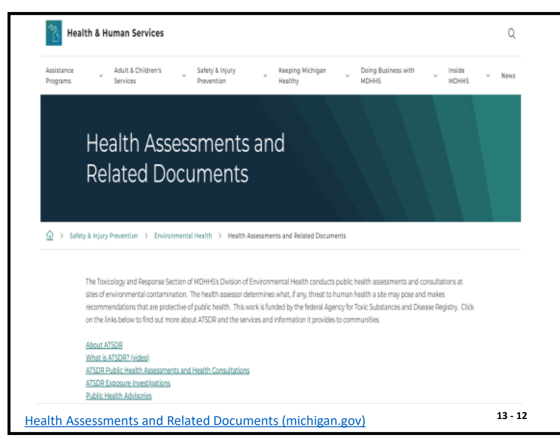
Health & Human Services
Assistance Programs
Adult & Children's Services
Safety & Injury Prevention
Keeping Michigan Healthy
Doing Business with MDHHS
Inside MDHHS
News
Health Assessments and Related Documents
Safety & Injury Prevention › Environmental Health › Health Assessments and Related Documents
The Toxicology and Response Section of MDHHS's Division of Environmental Health conducts public health assessments and consultations at sites of environmental contamination. The health assessor determines what, if any, threat to human health a site may pose and makes recommendations that are protective of public health. This work is funded by the federal Agency for Toxic Substances and Disease Registry. Click on the links below to find out more about ATSDR and the services and information it provides to communities.
About ATSDR
What is ATSDR? (video)
ATSDR Public Health Assessments and Health Consultations
ATSDR Exposure Investigations
Public Health Advisories
Health Assessments and Related Documents (michigan.gov)
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Health Consultation

Evaluation of Exposure to Landfill Gases in Ambient Air

BRIDGETON SANITARY LANDFILL

BRIDGETON, ST. LOUIS COUNTY, MISSOURI

Prepared by the
Missouri Department of Health and Senior Services
Division of Community and Public Health
Bureau of Environmental Epidemiology

August 11, 2022

Prepared under a Cooperative Agreement with the
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Office of Capacity Development and Applied Prevention Science
Atlanta, Georgia, 30333

landfill-hc-508.pdf (mo.gov)

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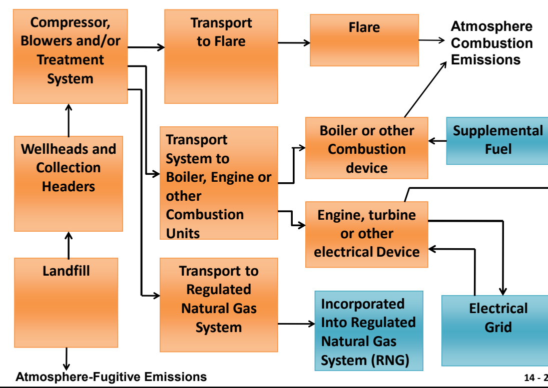
Collection and Control of Landfill Gas Emissions

14 - 1



14 - 2

Standards for Air Emissions from Municipal Solid Waste Landfills

- 60.762 Standards for air emissions from municipal solid waste landfills.
  (b) Each owner or operator of an MSW landfill having a design capacity equal to or greater than 2.5 million megagrams and 2.5 million cubic meters, shall either comply with paragraph (b)(2) of this section or calculate an NMOC emission rate for the landfill using the procedures specified in § 60.764.

Test methods and procedures

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Standards for Air Emissions from Municipal Solid Waste Landfills

- The NMOC emission rate shall be recalculated annually, except as provided in § 60.767(b)(1)(ii) of this subpart. The owner or operator of an MSW landfill subject to this subpart with a design capacity greater than or equal to 2.5 million megagrams and 2.5 million cubic meters is subject to part 70 or 71 permitting requirements.

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Standards for Air Emissions from Municipal Solid Waste Landfills

- 60.762 (b)(A) If the calculated NMOC emission rate is equal to or greater than 50 (34) megagrams per year, the owner or operator shall:
  (i) Submit a collection and control system design plan prepared by a professional engineer to the Administrator within 1 year:
  (A) The collection and control system as described in the plan shall meet the design requirements of paragraph (b)(2)(ii) of this section.

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Standards for Air Emissions from Municipal Solid Waste Landfills

- (B) The collection and control system design plan shall include any alternatives to the operational standards, test methods, procedures, compliance measures, monitoring, recordkeeping or reporting provisions of §§ 60.763 through 60.768 proposed by the owner or operator.

14 - 6

Standards for Air Emissions from Municipal Solid Waste Landfills

- **(C) The collection and control system design plan shall either conform with specifications for active collection systems in § 60.769 or include a demonstration to the Administrator's satisfaction of the sufficiency of the alternative provisions to § 60.769**

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(D) The Administrator shall review the information submitted under paragraphs (b)(2)(i) (A),(B) and (C) of this section and either approve it, disapprove it, or request that additional information be submitted. Because of the many site-specific factors involved with landfill gas system design, alternative systems may be necessary. A wide variety of system designs are possible, such as vertical wells, combination horizontal and vertical collection systems, or horizontal trenches only, leachate collection components, and passive systems.

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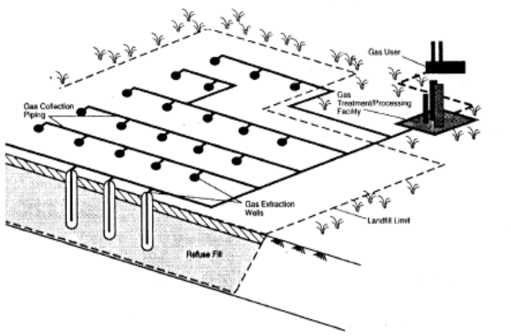
Example of an Interior Gas Collection/Recovery System



Source: Emcon, 1981

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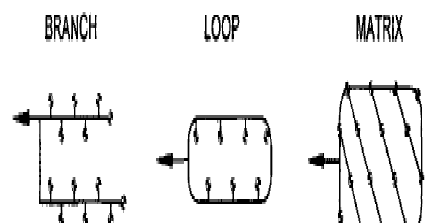
Header Routing Options



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Vertical Extraction Wells Versus Horizontal Collectors

- Either vertical wells and/or horizontal collectors can be installed while refuse is being placed.
- Horizontal collectors need to be installed as refuse is being placed. Cannot be installed after waste is in place except as surface collectors and are more sensitive to settlement and watering in.
- Vertical wells will generally produce better quality LFG (higher methane content).

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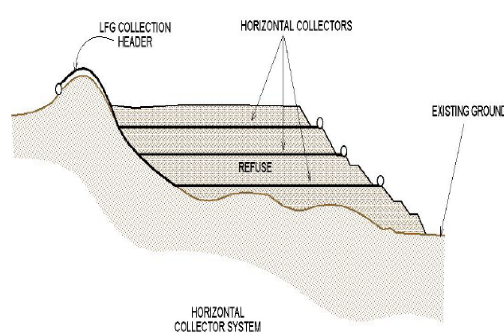
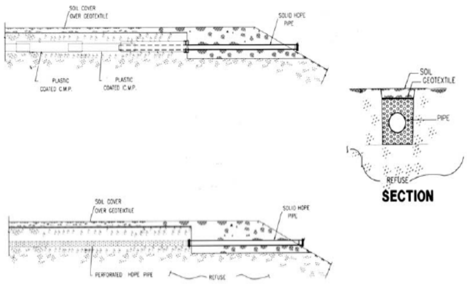
Typical Horizontal Collector Layout



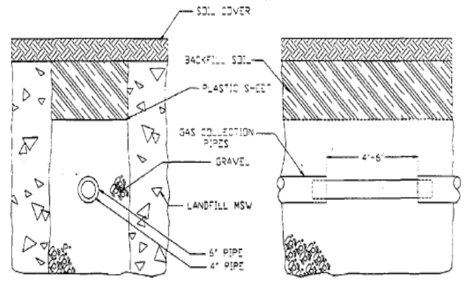
14 - 12

Typical Horizontal Collector Details



14 - 13

Typical Horizontal Well Detail, Front & Side Profiles



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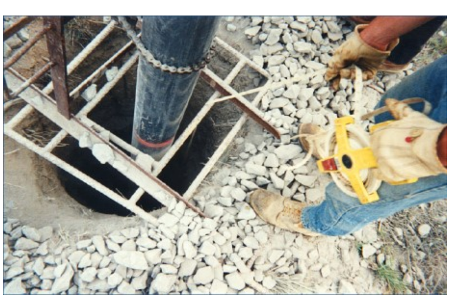

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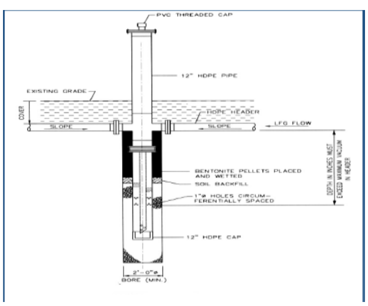
Condensate Drain



14 - 21

Standards for Air Emissions from Municipal Solid Waste Landfills

- **(A) An active collection system shall:**
  (1) Be designed to handle the maximum expected gas flow rate from the entire area of the landfill that warrants control over the intended use period of the gas control or treatment system equipment;
  (2) Collect gas from each area, cell, or group of cells in the landfill in which the initial solid waste has been placed for a period of:
  (i) 5 years or more if active; or
  (ii) 2 years or more if closed or at final grade.
  (3) Collect gas at a sufficient extraction rate;
  (4) Be designed to minimize off-site migration of subsurface gas.

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<u>§ 60.769 Specifications for active collection systems.</u>
(a) Each owner or operator seeking to comply with § 60.762(b)(2)(i) shall site active collection wells, horizontal collectors, surface collectors, or other extraction devices at a sufficient density throughout all gas producing areas using the following procedures unless alternative procedures have been approved by the Administrator as provided in §60.762(b)(2)(i)(C) and (D):

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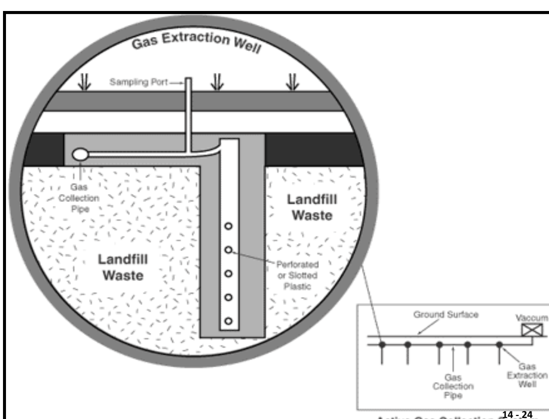

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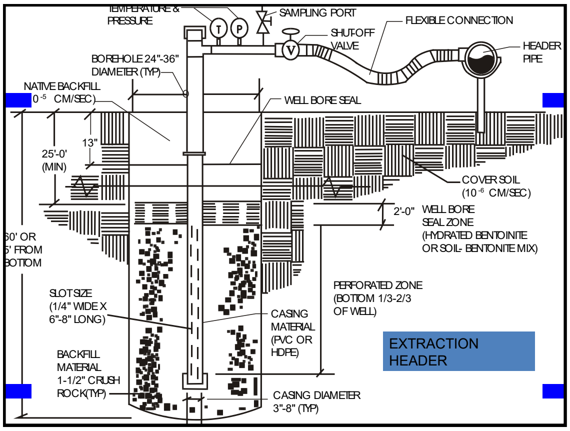

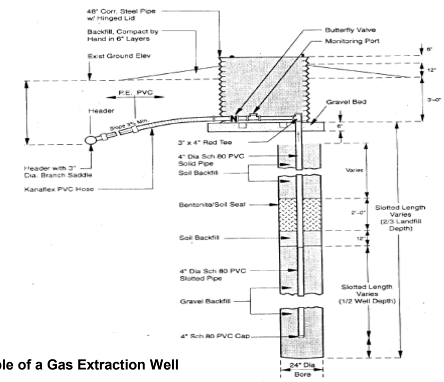

Example of a Gas Extraction Well

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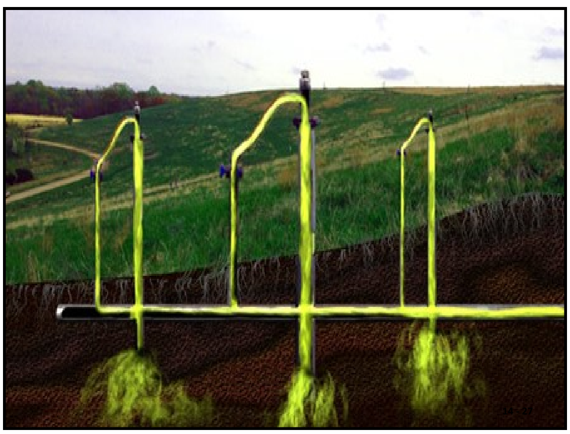
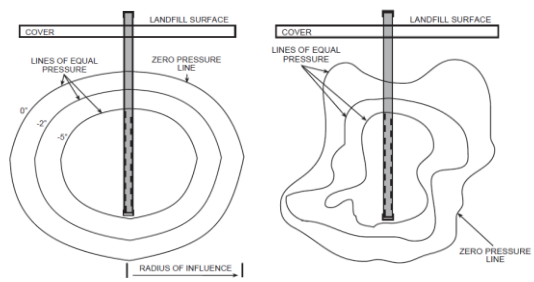


Theoretical and Actual Radius of Influence (ROIs)



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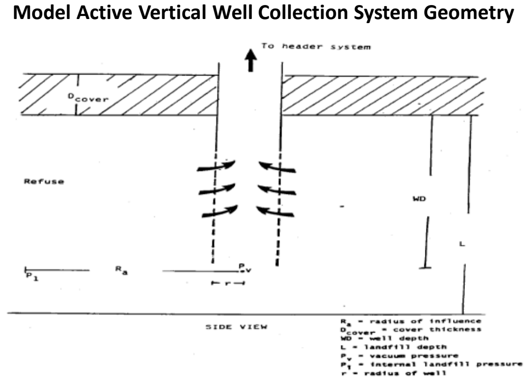
Model Active Vertical Well Collection System Geometry



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Radius of Influence Equation

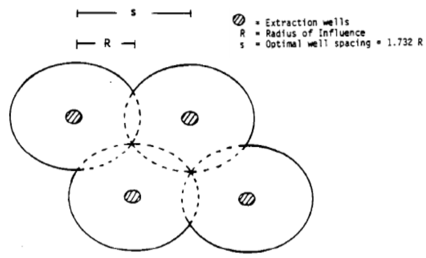
$$R_a = (Q_{w,a}\ \text{Design Capacity}/\pi L\ \rho_{refuse}\ Q_{gen}\ E_a)^{1/2}$$

where,

- R_a = radius of influence for active collection systems, m
- $Q_{w,a}$ = landfill gas flowrate per well, m^3/sec
- Design Capacity = design capacity of the landfill, kg
- π = 3.14
- ρ_{refuse} = refuse density, kg/m^3
- L = landfill depth, m
- Q_{gen} = peak landfill gas generation rate, m^3/sec
- E_a = fractional collection efficiency of active well systems

14 - 30

Zones of Influence for Extraction Wells



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(1) The collection devices within the interior and along the perimeter areas shall be certified to achieve comprehensive control of surface gas emissions by a professional engineer. The following issues shall be addressed in the design: depths of refuse, refuse gas generation rates and flow characteristics, cover properties, gas system expandability, leachate and condensate management, accessibility, compatibility with filling operations, integration with closure end use, air intrusion control, corrosion resistance, fill settlement, and resistance to the refuse decomposition heat.

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Treatment of LFG

- **The regulations at 40 CFR Part 60.762(b)(2)(iii) state that collected landfill gas is required to be routed to a control system that complies with the requirements in either: A) an open flare; B) a control system or enclosed combuster designed to reduce NMOC; or C) a treatment system that processes the collected gas for subsequent sale or use. The landfill gas has been treated for sale or use under 60.762(b)(2)(iii)(C). U.S. EPA has made several determinations that compression, de-watering, and filtering the landfill gas down to at least 10 microns is considered treatment for the purposes of 60.762(b)(2)(iii)(C).**

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Control System

- 60.762(b)(2)(iii)
- Control system. Route all the collected gas to a control system that complies with the requirements in either paragraph (b)(2)(iii)(A), (B), or (C) of this section. (A) A non-enclosed flare designed and operated in accordance with the parameters established in §60.18, except as noted in §60.764(e); or

14 - 35

Treatment of LFG

- **US EPA has determined that once the landfill gas is treated, the treated gas is no longer subject to the requirements of the NSPS and, in turn, the NESHAP.**
- **However, emissions from any atmospheric vent from the gas treatment system, including any compressor, are subject to the requirements of 40 CFR 60.752(b)(2)(iii)(A) and (B), as well as the NESHAP. This does not include exhaust from an energy recovery device.**

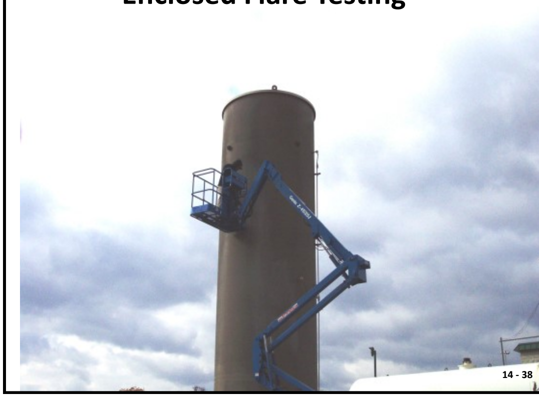
http://www.epa.gov/compliance/monitoring/programs/caa/adi.html

14 - 36

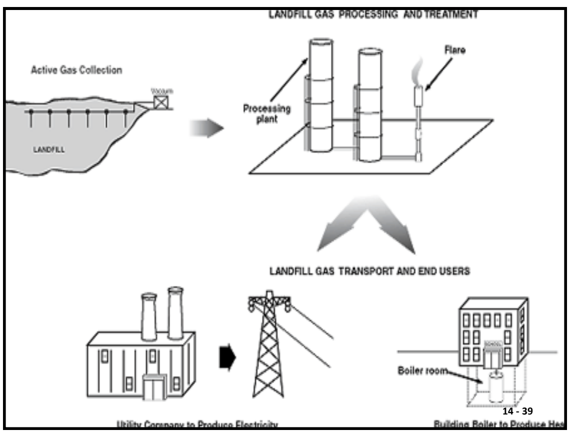
(*2*) The control device shall be operated within the parameter ranges established during the initial or most recent performance test. The operating parameters to be monitored are specified in
§ 60.756 (WWW) (60.766)(XXX);

14 - 37

Enclosed Flare Testing



14 - 38



14 - 39

60.753 (60.763) Operational standards for collection and control systems.
Each owner or operator of an MSW landfill with a gas collection and control system used to comply with the provisions of
§ 60.752(b)(2)(ii) (60.763(a)) of this subpart shall:
(a) Operate the collection system such that gas is collected from each area, cell, or group of cells in the MSW landfill in which solid waste has been in place for:
(1) 5 years or more if active; or
(2) 2 years or more if closed or at final grade;

14 - 40

(b) Operate the collection system with negative pressure at each wellhead <u>except</u> under the following conditions:
(1) A fire or increased well temperature.
The owner or operator shall record instances when positive pressure occurs in efforts to avoid a fire. These records shall be submitted with the annual reports as provided in § 60.757(f)(1);

14 - 41

(c) Operate each interior wellhead in the collection system with a landfill gas temperature less than 55 °C (< 62.8°C) and with either a nitrogen level less than 20 percent or an oxygen level less than 5 percent (only for WWW).
The owner or operator may establish a higher operating temperature, nitrogen, or oxygen value at a particular well.
A higher operating value demonstration shall show supporting data that the elevated parameter does not cause fires or significantly inhibit anaerobic decomposition by killing methanogens.

14 - 42

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14 - 44

14 - 45

Surface Scan

- **(60.763(d)** Operate the collection system so that the methane concentration is less than 500 parts per million above background at the surface of the landfill. To determine if this level is exceeded, the owner or operator shall conduct surface testing around the perimeter of the collection area and along a pattern that traverses the landfill at 30 meter intervals and where visual observations indicate elevated concentrations of landfill gas, such as distressed vegetation and cracks or seeps in the cover.**

14 - 46

Surface Scan (60.755)(60.765)

- **The owner or operator may establish an alternative traversing pattern that ensures equivalent coverage. A surface monitoring design plan shall be developed that includes a topographical map with the monitoring route and the rationale for any site-specific deviations from the 30 meter intervals. Areas with steep slopes or other dangerous areas may be excluded from the surface testing.**

14 - 47

Surface Scan

- Surface emission monitoring shall be performed in accordance with section 4.3.1 of Method 21 of appendix A of this part, except that the probe inlet shall be placed within 5 to 10 centimeters of the ground. Monitoring shall be performed during typical meteorological conditions.
- The owner or operator must use a wind barrier, similar to a funnel, when onsite average wind speed exceeds 4 miles per hour or 2 meters per second or gust exceeding 10 miles per hour. Average on-site wind speed must also be determined in an open area at 5-minute intervals using an on-site anemometer with a continuous recorder and data logger for the entire duration of the monitoring event. The wind barrier must surround the SEM monitor, and must be placed on the ground, to ensure wind turbulence is blocked. SEM cannot be conducted if average wind speed exceeds 25 miles per hour. (Tier 4)

14 - 48

Surface Scan

- (4) Any reading of 500 parts per million or more above background at any location shall be recorded as a monitored exceedance and the actions specified in paragraphs (c)(4) (i) through (v) of this section shall be taken. As long as the specified actions are taken, the exceedance is not a violation of the operational requirements of § 60.753(d).

14 - 49

Surface Scan Frequency (60.757)

- (f) Each owner or operator seeking to demonstrate compliance with § 60.755(c), shall monitor surface concentrations of methane according to the instrument specifications and procedures provided in § 60.765(d). Any closed landfill that has no monitored exceedances of the operational standard in three consecutive quarterly monitoring periods may skip to annual monitoring. Any methane reading of 500 ppm or more above background detected during the annual monitoring returns the frequency for that landfill to quarterly monitoring.

14 - 50

Reporting Emissions from Landfills

Gas collection systems are not 100 percent efficient in collecting landfill gas, so emissions of CH4 and NMOCs at a landfill with a gas recovery system still occur. To estimate controlled emissions of CH4, NMOCs, and other constituents in landfill gas, the collection efficiency of the system must first be estimated. Reported collection efficiencies typically range from 60 to 85 percent, with an assumed average of 75 percent. If site-specific collection efficiencies are available, they should be used instead of the 75 percent average.

14 - 51

From Background AP-42 Document

- Equation (1) in the AP-42 Section is used to estimate emissions from an uncontrolled landfill. In this update, a factor of 1.3 was added to Equation (1) to account for the fact that L_O is determined by the amount of gas collected by LFG collection systems. The design of these systems will typically result in a gas capture efficiency of only 75%. Therefore, 25% of the gas generated by the landfill is not captured and included in the development of L_O.

14 - 52

From Background AP-42 Document

- The ratio of total gas to captured gas is a ratio of 100/75 or equivalent to 1.3. An analysis of the efficiency of typical LFG collection systems is presented in Appendix E. Previous equation being used did not account for total emissions which includes the quantity of gas that is collected plus any fugitive loss from leaks that can occur from header pipes, extraction wells, side slopes, and landfill cover material.

14 - 53

Municipal Solid Waste Landfills, Volume 1: Summary of Requirements for New Source Performance Standards and Emission Guidelines | US EPA

14 - 54

$$\begin{matrix}\text{UnControlled}\\ \text{Landfill}\\ \text{Emissions}\end{matrix} = P\left(1 - \frac{\begin{matrix}\text{Percent}\\ \text{Collection}\\ \text{Efficiency}\end{matrix}}{100}\right) + P\left(\frac{\begin{matrix}\text{Percent}\\ \text{Collection}\\ \text{Efficiency}\end{matrix}}{100}\right) * \left(1 - \frac{\begin{matrix}\text{Percent}\\ \text{Control}\\ \text{Efficiency}\end{matrix}}{100}\right)$$

14 - 55

VOC emissions from Landfill A are estimated to be 3,197 cubic meters per year.
Average collection efficiency of the landfill gas recovery system is not known at Landfill A, so a 75-percent collection efficiency rate is assumed. The collected landfill gas is controlled by a flare, which has a control efficiency for NMOCs of 83.16 percent.
Uncontrolled NMOC Emissions = 3,197 m^3 * [1 - 0.75] + 3,197 m^3 * [0.75] * [1 - 0.8316]

= 799.25 m^3 + 3,197 m^3 * 0.1263
= 799.25 m^3 + 403.78 m^3
= 1,203 m^3

14 - 56

LFG COLLECTION EFFICIENCY IS IMPROVING IN WISCONSIN

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ABSTRACT
Wisconsin has 32 landfills that actively receive municipal solid waste (MSW). Twenty-four (24) of these landfills are required to collect landfill gas (LFG) via active landfill gas collection and control systems (GCCS). A study was conducted to determine how the LFG collection efficiency at these 24 landfills is changing over time.

The LFG industry has long struggled with calculating the "real" LFG collection efficiency. While this study does not supply the "real" LFG collection efficiency, it does utilize a qualitative approach to track efficiency over time to reveal trends in the data. This is the first study of its type to review LFG collection efficiency trends on a statewide level. This approach can be replicated by other States to determine their statewide LFG collection efficiency trend and to help focus on sectors that need improvement.

Results of this study confirm that Wisconsin's' LFG collection efficiency is improving (refer to Table 1). For the years 2000 through 2004, the statewide LFG collection efficiency continuously improved from 77.3% to 85%. Further subdivision of the 24 landfills was made into 2 groups: 1) landfills owned by private industry, and 2) landfills owned by municipalities. These results are also reported in Table 1.

Wisconsin's 24 landfills accepted over 7.5 million tons of decomposable waste in year 2004. This tonnage data, dating back to Year 1988, was input into the EPA LANDGEM model to estimate the statewide LFG generation. Wisconsin landfills were then contacted to obtain their annual LFG collection rates for the years 2000 through 2004.

This study concluded that:
- LFG collection efficiency in Wisconsin is improving over time, even as more and more waste is deposited in landfills every year.
- The 2004 LFG collection efficiency at 24 landfills averaged 85%.
- The LFG collection efficiency of the privately owned and municipally owned landfills in Wisconsin is generally the same.

Table 1 – Wisconsin's Trend in LFG Collection Efficiency

Year	EPA LFG Generation Rate k =.04 & Lo =100 (scfy)	LFG Collection Rate (scfy)	LFG Collection Efficiency
All 24 Landfills			
2000	11,011,536,242	8,510,869,218	77.3%
2001	12,186,264,192	9,649,623,435	79.2%
2002	13,515,657,032	10,879,087,006	80.5%
2003	14,697,752,437	11,828,449,205	80.5%
2004	15,846,366,701	13,476,494,679	85.0%
Total	**67,257,576,605**	**54,344,523,542**	**80.8%**
9 Municipally Owned Landfills			
2000	2,753,612,886	2,023,757,382	73.5%
2001	2,916,809,855	2,265,507,691	77.7%
2002	3,035,436,221	2,280,396,975	75.1%
2003	3,158,481,798	2,451,376,080	77.6%
2004	3,275,611,698	2,717,645,580	83.0%
Total	**15,139,952,458**	**11,738,683,707**	**77.5%**
15 Privately Owned Landfills			
2000	8,257,923,356	6,487,111,836	78.6%
2001	9,269,454,337	7,384,115,744	79.7%
2002	10,480,220,811	8,598,690,031	82.0%
2003	11,539,270,640	9,377,073,125	81.3%
2004	12,570,755,004	10,758,849,099	85.6%
Total	**52,117,624,147**	**42,605,839,835**	**81[illegible]**

14 - 57

Summary of the Requirements for the New Source Performance Standards and Emission Guidelines for Municipal Solid Waste Landfills - APPENDIX E

Collection System Design Plans

- All owners and operators of affected landfills are required to submit to the Administrator a collection and control system design plan prepared by a professional engineer. This appendix provides a summary of the design plan requirements for all collection systems: active collection systems that meet the requirements of §60.759 as well as alternate collection systems. It also provides guidance on what to look for in such plans and case study examples.

14 - 58

Specifications for Active Collection Systems

- Owners or operators seeking to comply with the specifications for active collectionsystems in §60.759 must meet the following:
- (1) Demonstrate that the siting of active collection wells, horizontal collectors, surface collectors, or other extraction devices is of sufficient density throughout all gas producing areas.
- (2) Devices located within the interior and along the perimeter must be certified by a professional engineer to achieve uniform control of surface gas emissions.

14 - 59

- (3) Design plans must address the 13 issues listed in Table E-1.
- (4) Collection system siting should be of sufficient density to address landfill gas migration issues, and augmentation of the system through the use of active or passive systems at the perimeter or exterior.

14 - 60

- (5) The system should control all gas producing areas except those that are excluded because either (1) they are segregated and shown to contain asbestos or non-degradable material, (documentation must include nature, location, amount of asbestos or non-degradable material deposited, and date of deposition) or (2) they are nonproductive areas and can be shown to contribute less than 1 percent of the total amount of NMOC emissions from the landfill (amount, location, and age of the material must be documented).

14 - 61

- (6) To qualify for exclusion based on non-productivity, emissions must be calculated for each section proposed for exclusion, and the sum of all such sections must be compared with the NMOC emission estimate for the entire landfill. Emissions from each section must be calculated according to the following equation, from §60.759(a)(3)(ii) of the NSPS:
- $Q_i = 2\ k\ L_o\ M_i\ (e^{-kti})\ (C_{NMOC})\ (3.6 \times 10\text{-}9)$

14 - 62

- The values for k and C_{NMOC} determined in field testing must be used, if field testing has been performed in determining the NMOC emission rate or the radii of influence. The radii of influence is the distance from the well center to a point in the landfill where the pressure gradient applied by the blower or compressor approaches zero. If field testing has not been performed, default values for k, Lo and C_{NMOC} of 0.05/year (0.02/year in arid areas), 170 m3/Mg, and 4,000 ppmv, respectively, must be used as provided for Tier 1 calculations from §60.754(a)(1)

14 - 63

TABLE E-1. LIST OF DESIGN PLAN REQUIREMENTS

	Issue Description
1.	Depth(s) of refuse
2.	Refuse gas generation rates and flow characteristics
3.	Cover properties
4.	Gas system expandability
5.	Leachate and condensate management
6.	Accessibility
7.	Compatibility with filling operations
8.	Integration with closure end use
9.	Air intrusion control
10.	Corrosion resistance
11.	Fill settlement
12.	Resistance to the refuse decomposition heat
13.	Topographical map of the surface area and proposed surface monitoring route [required in § 60.753(d)]

14 - 64

- For landfills located in geographical areas with a 30-year annual average precipitation of less than 25 inches, as measured at the nearest representative official meteorological site, a k value of 0.02 per year should be used as provided in the Tier 1 calculations in §60.754(a)(1). Note: The mass of non-degradable solid waste contained within the given section may be subtracted from the total mass of the section when estimating emissions provided the nature, location, age, and amount of the non-degradable material is documented as indicated in paragraph (5) above.

14 - 65

- (7) The gas extraction components must be constructed of polyvinyl chloride (PVC), high density polyethylene (HDPE) pipe, fiberglass, stainless steel, or other nonporous corrosion-resistant material.
- (8) The extraction components must be of suitable dimensions to: convey projected amounts of gases; withstand installation, static, and settlement forces; and withstand planned overburden or traffic loads.

14 - 66

- (9) The collection system must be capable of any expansion needed to comply with emission and migration standards.
- (10) Collection devices such as wells and horizontal collectors must be perforated to allow gas entry without head loss sufficient to impair performance across the intended extent of control. Perforations must be situated to prevent excessive air infiltration.
- (11) Vertical wells cannot endanger underlying liners and must address the occurrence of water within the landfill

14 - 67

- (12) Holes and trenches must be of sufficient cross-section for proper construction and completion. For example: the design should call for the centering of pipes and allow for the placement of gravel backfill.
- (13) Collection devices must be constructed of PVC, HDPE pipe, fiberglass, stainless steel, or other nonporous corrosion-resistant material and must not allow for air intrusion into the cover, refuse into the collection system, or landfill gas into the atmosphere.
- (14) Any gravel used around the pipe perforations should be large enough to prevent penetration or blockage of the perforations.

14 - 68

- (12) Holes and trenches must be of sufficient cross-section for proper construction and completion. For example: the design should call for the centering of pipes and allow for the placement of gravel backfill.
- (13) Collection devices must be constructed of PVC, HDPE pipe, fiberglass, stainless steel, or other nonporous corrosion-resistant material and must not allow for air intrusion into the cover, refuse into the collection system, or landfill gas into the atmosphere.
- (14) Any gravel used around the pipe perforations should be large enough to prevent penetration or blockage of the perforations.

14 - 69

- (15) The connections for collection devices may be above or below ground, but must include: a positive closing throttle valve, necessary seals and couplings, access couplings, and at least one sampling port.
- (16) The system must convey the landfill gas to a control system through the collection header pipe(s). The gas mover equipment must be of a size capable of handing the maximum gas generation flow rate expected over the intended use period of the equipment.

14 - 70

- (17) For existing systems the maximum flow rate must be determined by existing flow data, or by using the following equation. New systems must also use the equation. Two equations are provided for determining the maximum flow rate: one equation for sites with an unknown year-to-year solid waste acceptance rate, and one equation for sites with a known year-to-year solid waste acceptance rate. A combination of the equations can be used if the acceptance rate is known for only part of the life of the landfill.
- For sites with unknown year-to-year solid waste acceptance rate:

14 - 71

- Qm = 2Lo R (e-kc - e-kt)
- where,

Qm = maximum expected gas generation flow rate, m3/yr

Lo = methane generation potential, m3/Mg solid waste

R = average annual acceptance rate, Mg/yr

k = methane generation rate constant, year-1

t = age of the landfill at equipment installation plus the time the owner or operator intends to use the gas mover equipment or active life of the landfill, whichever is less. If the equipment is installed after closure, t is the age of the landfill at installation, years

c = time since closure, years (for an active landfill c = O and e^{-kc} = 1)

14 - 72

- For sites with known year-to-year solid waste acceptance rate:

$$Q_M = \sum_{i=1}^{n} \left(2 k L_o M_i \left(e^{-kt_i}\right) \right)$$

where,

Q_M = maximum expected gas generation flow rate, m3/yr

k = methane generation rate constant, year-1

Lo = methane generation potential, m3/Mg solid waste

M_i = mass of solid waste in the ith section, Mg

t_i = age of the ith section, years

14 - 73

Specifications for the Active Collection Systems

- In reviewing design plans for active collection systems designed to meet §60.769, it is important to ensure that adherence to each of the requirements in the section entitled "Specifications for Active Collection Systems" is adequately demonstrated. In reviewing alternate plans (for active or passive systems), it is important to ensure that the requirements listed in the "Design Plan Requirements" section are followed.

14 - 74

Review of Plans

- It is also important to recognize that the rule includes operational standards along with monitoring and reporting requirements to ensure that landfill gas is extracted from the landfill at a sufficient rate. Section 60.763 requires operation of collection systems so that the methane concentration is less than 500 ppmv at all points around the perimeter of the collection area and along a pattern that traverses the landfill at 30-meter intervals.

14 - 75

Control of LFG

(A) An open flare designed and operated in accordance with § 60.18;

(B) A control system designed and operated to reduce NMOC by 98 weight percent, or, when an enclosed combustion device is used for control, to either reduce NMOC by 98 weight percent or reduce the outlet NMOC concentration to less than 20 parts per million by volume, dry basis as hexane at 3 percent oxygen. The reduction efficiency or parts per million by volume shall be established by an initial performance test to be completed no later than 180 days after the initial startup of the approved control system using the test methods specified in § 60.754(d)

14 - 76

LFG Control & Treatment

- Combustion

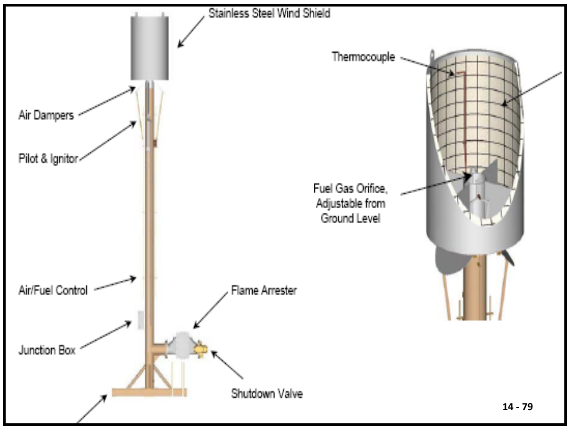
<u>Energy Recovery</u> **OR** **<u>No Energy Recovery</u>**

Gas turbines
Internal combustion engines
Boiler-to-steam turbine systems
Fuel cells

Flares (open or enclosed)

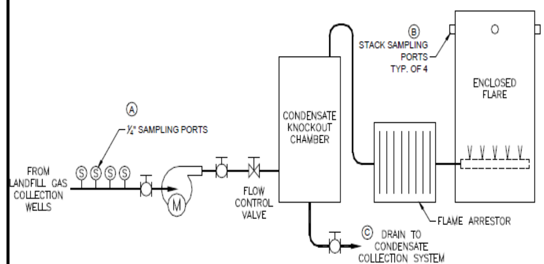
- **<u>Purification</u>**
  - **Use of adsorption, absorption, and membranes to remove water (H2O), CO2, H2S,NMOCs, and siloxanes.**
    - **Can process LFG to pipeline quality natural gas**

14 - 78



14 - 79

Simplified Flare Process Flow Diagram and Sampling Points



14 - 80

Blower Skid

Multi-Stage Blower

Raw Landfill Gas Collection Pipe

14 - 83

Sampling Operations at the Raw Landfill Gas Pipe Inlet

14 - 84

Sampling Operations at the Enclosed Flare

14 - 85

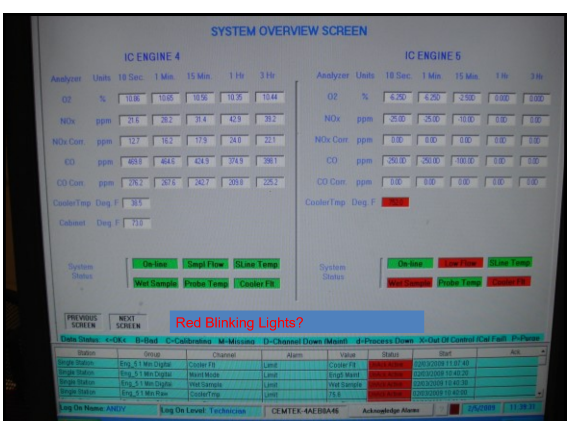
Enclosed Flare with blower

14 - 86

Energy Production

- ✓ Internal combustion engine
- ✓ Turbines
- ✓ Boilers
- ✓ Pipeline
- ✓ Fuel Cell

87



Electricity Generation Technology

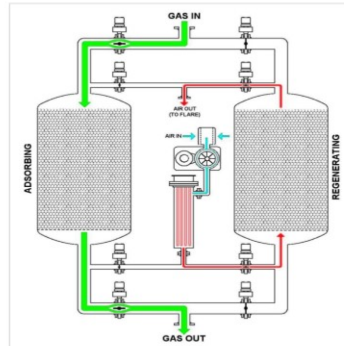
	IC Engines	Turbines	Boilers
Advantages	* Low cost * High efficiency * Common technology	* Corrosion resistant * Low O&M costs * Small physical size * Low Nox emissions	* Corrosion resistant * Can handle gas Composition variations * Low NOx emissions
Disadvantages	* Problems due to PM buildup * Corrosion of engine Parts and catalysts * High Nox emissions	* Inefficient at partial load * High parasitic loads Due to high compression req. * High capital costs	* Innefficient at smaller sizes * Requires large amounts of clean water

NMOC CONTROL EFFICIENCY DATA ANALYSIS SUMMARY AP-42 Background Document

	Number of Data Points	Min (%)	Max (%)	Mean (%)	Standard Deviation (%)	95% Confidence Interval (± %)
Boiler	5	95.9	99.6	98.6	1.6	1.4
Flare	25	85.8	100.0	97.7	3.4	1.3
Engine	3	94.6	99.7	97.2	2.6	2.9
Avg of Boiler, Engine, Flare				97.8		
Turbine	2	91.5	97.3	94.4	4.1	134.8

14 - 91

Diagram of a Siloxane Removal System



14 - 92

Siloxane removal systems at the Lorraine power station at Oberlin, Ohio

14 - 93

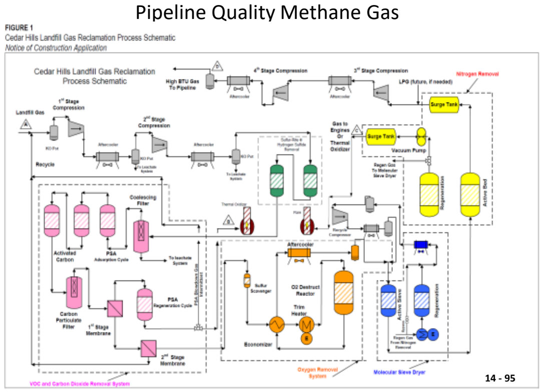
Types of H2S Treatment of LFG

- Iron Sponge
  - Dry Media of Iron-Oxide on Wood chips
  - Does best with a warm wet gas and Oxygen
- Sulfatreat (iron oxide on ceramic beads)
  - Does best with warm, humid landfill gas with a small amount of Oxygen
- LO CAT® SulFerox
  - Chelated Iron Treatment System

H2S Treatment of Landfill Gas at the Roosevelt Landfill (epa.gov)

14 - 94

Gas Processing System for Taking LFG to to Produce Pipeline Quality Methane Gas



14 - 95

Carbon Adsorber – Fixed Bed Examples

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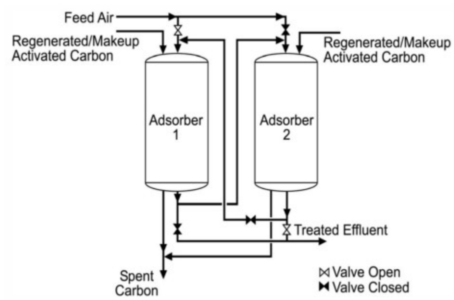
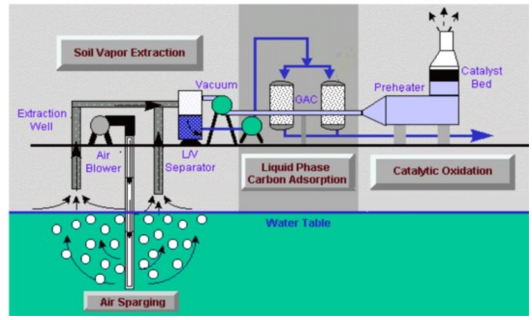
Schematic of a Fluid-Bed Adsorber



14 - 97



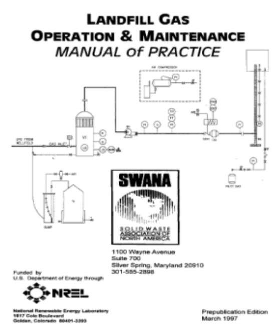
[2.3.5 Common Treatment Train for Nonhalogenated VOCs (frtr.gov)]

14 - 98

- [Biogas Siloxanes & VOC Removal (airscience.ca)]

14 - 99

Helpful Publication



http://www.nrel.gov/docs/legosti/fy97/23070.pdf

14 - 100

Odors, Emissions and Complaints Associated With Landfills

15 - 1

Air Pollution Complaints

- Complaints are triggered by:
- Offensive odors
- Opacity
- Particle fallout
- Fugitive dust
- Damage
- Episodal release
- Open burning
- General conditions

15 - 2

Questions to ask Complainant

- **Name**
- **What, where and when**
- **Current condition**
- **Other occurrences**
- **Other people**
- **Specific data**

3

Difficulties in Identification and Mitigation of Odors

S Chicago Tribune, Tuesday, August 24, 1999 Section 2 5

Noses know what IEPA can't detect

By Cornelia Grumman
TRIBUNE STAFF WRITER

On nights the wind blows just so, a putrid odor wafts over the neighborhood surrounding Evanston Hospital, assaulting the noses of residents to such a degree that some, like Margaret Kelly, have started logging their insomnia in notebooks and complaining to state officials.

"It smells like 50 sick skunks coming through the window," said Kelly, who started taking olfactory offense in July. "It's awful."

The Illinois Environmental Protection Agency has launched an investigation into whether the medical center's approved, on-site incineration of infectious waste—including blood products, syringes and body organs—is to blame for the foul odor.

Meanwhile, Evanston firefighters have responded to four middle-of-the-night stench calls from neighborhood residents this summer without being able to confirm the presence of odd smells, said Evanston Fire Marshal Alan Berkowsky.

Recent tests of the incinerator's emissions show it to be well within state and federal guidelines, said Evanston Northwestern Healthcare spokeswoman Joan Trezek. And hospital employees dispatched in recent weeks on middle-of-the-night "sniff and snort patrols" found no problems, she said.

"They're just sticking their noses in the air," said Trezek. "At this point, we don't know what's causing the problem."

The odor complaints come at a time hospitals across the country are under increasing pressure to reduce or eliminate on-site incineration, according to Joanna Hoelscher, policy analyst for Citizens for a Better Environment.

In Illinois alone, the number of on-site hospital incinerators has plummeted from nearly 200 in the early 1990s to about 100 today, with more hospitals opting to contract with haulers who cart the waste away, recycle more or use new methods of sterilization such as intense heat autoclaving.

New state and federal regulations go into effect in a year, tightening restrictions on what's called "red bag" burning of infectious hospital waste, and according to Julie Neposchlan of the state EPA, when that happens, "it may be more beneficial for some hospitals not to operate their own incinerator. . . .".

So-called red-bag waste does not necessarily produce foul smells when burned, according to Bill Franek, compliance manager of the Cook County Environmental Control Department. Franek has twice sent an inspector to the Evanston site, once to check for odors and another time to check how well the incinerator was operating.

Both times, he found nothing amiss, Franek said.

"We haven't determined that the odor is actually coming from the hospital," he said.

For more than a decade, the hospital has held a permit to incinerate its own medical waste, according to James Wolinski, Evanston's community development director, allowing it to burn up to 1,000 pounds of medical waste an hour at a temperature of 1,400 degrees Fahrenheit.

Tribune freelance writer Brian Cox contributed to this report.

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Odor Complaints in South Carolina

- South Carolina environmental officials are demanding that a cardboard factory in Catawba lower gas emissions that are making the area smell like rotten eggs.
- The New-Indy factory is belching out too much of a "noxious air contaminant," making parts of Lancaster and York counties and neighboring areas in North Carolina, including Charlotte, reek, according to the South Carolina Department of Health and Environmental Control.
- HEC said that it began receiving complaint about the odor in February and to date has received 17,135 complaints, an "unprecedented number" about an odor.
- The studies also found that wastewater, "sludge storage" and a landfill connected to the factory may contain sulfurs, adding to the bad smell. These also need to be tested and corrected, DHEC ordered.

15 - 5

Landfill Gas Emission Sources

Total gas generated

Gas collection system

Treatment devices (flares, gas-to-energy boilers, etc.)

Uncollected gas Landfill surface (cover, fissures, around wells, etc.)

Migration out of waste boundary off site?

15 - 6

Landfill gas odors are produced by bacterial or chemical processes and can emanate from both active or closed landfills. These odors can migrate to the surrounding community. Potential sources of landfill odors include sulfides, ammonia, and certain NMOCs, if present at concentrations that are high enough. Landfill odors may also be produced by the disposal of certain types of wastes, such as manures and fermented grains.

15 - 7

Sulfides

Hydrogen sulfide, dimethyl sulfide, and mercaptans are the three most common sulfides responsible for landfill odors. These gases produce a very strong rotten-egg smell—even at very low concentrations. Of these three sulfides, hydrogen sulfide is emitted from landfills at the highest rates and concentrations.

Humans are extremely sensitive to hydrogen sulfide odors and can smell such odors at concentrations as low as 0.5 to 1 part per billion (ppb). At levels approaching 50 ppb, people can find the odor offensive.

15 - 8

Sulfides (continued)

Average concentrations in ambient air range from 0.11 to 0.33 ppb (ATSDR 1999a). Information collected by the Connecticut Department of Health, the concentration of hydrogen sulfide in ambient air around a landfill is usually close to 15 ppb (CTDPH 1997; ATSDR 1999a).

hydrogen-sulfide_20180206.pdf (ohio.gov)

http://www.michigan.gov/deq/0,1607,7-135-3311_4111_4231-9162--,00.html

15 - 9

Ammonia

Ammonia is another odorous landfill gas that is produced by the decomposition of organic matter in the landfill. Ammonia is common in the environment and an important compound for maintaining plant and animal life. People are exposed daily to low levels of ammonia in the environment from the natural breakdown of manure and dead plants and animals. Because ammonia is commonly used as a household cleaner, most people are familiar with its distinct smell.

15 - 10

Ammonia

Humans are much less sensitive to the odor of ammonia than they are to sulfide odors.

The odor threshold for ammonia is between 28,000 and 50,000 ppb. Landfill gas has been reported to contain between 1,000,000 and 10,000,000 ppb of ammonia, or 0.1% to 1% ammonia by volume (Zero Waste America n.d.). Concentrations in ambient air at or near the landfill site are expected to be much lower.

15 - 11

Non-Methane Organic Compounds (NMOC's)

NMOC: Some NMOCs, such as vinyl chloride and volatile organic compounds (VOC's), may also cause odors.

In general, NMOCs are emitted at low (trace) concentrations and not unlikely to pose a severe odor problem.

However, many of these compounds are regulated as Hazardous Air Pollutants (HAP's) and/or VOC's in the regulations.

15 - 12

Landfill Gas Components and Odor Descriptions

Component	Odor Description	Odor Threshold (parts per billion)
Hydrogen Sulfide	Strong rotten egg smell	0.5 to 1
Ammonia	Pungent acidic or suffocating odor	1,000 to 5,000
Benzene	Paint-thinner-like odor	840
Dichloroethylene	Sweet, ether-like, slightly acrid odor	85
Dichloromethane	Sweet, chloroform-like odor	205,000 to 307,000
Ethylbenzene	Aromatic odor like benzene	90 to 600
Toluene	Aromatic odor like benzene	10,000 to 15,000
Trichloroethylene	Sweet, chloroform-like odor	21,400
Tetrachloroethylene	Sweet, ether- or chloroform-like odor	50,000
Vinyl Chloride	Faintly sweet odor	10,000 to 20,000

15 - 13

Landfill Gas Primer

An Overview for Environmental Health Professionals

http://www.atsdr.cdc.gov/hac/landfill/html/intro.html

November 2001

ATSDR
Agency for Toxic Substances and Disease Registry

Department of Health and Human Services
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation

15 - 14

Humans Sense of Smell

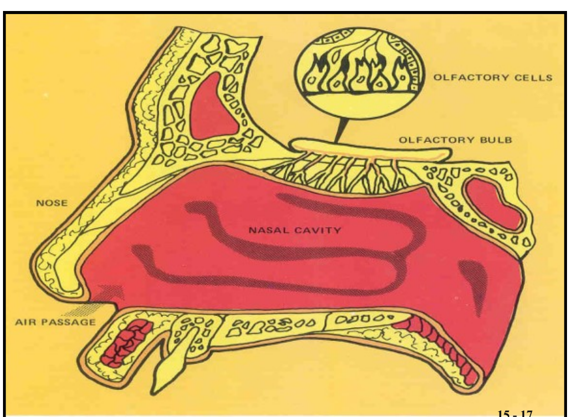
- How good is our sense of smell?
- Latest findings suggest we can detect over one trillion smells!
- We can only detect about 7.5 million colors.
- Humans have about 5–10 million Olfactory sensory neurons (OSNs) which are the main cell type in the olfactory epithelium. OSNs are small neurons located beneath a watery mucous layer in the epithelium.

15 - 15

Landfill Odors and Neighbors

Many people may find the odors emitted from a landfill and other sources offensive or unpleasant. In reaction to the odor, some people may experience nausea or headaches. Symptoms such as headaches and nausea can fade when the odor goes away. However, the effects on day-to-day life can be more lasting. Additionally, the frustration from the frequent odor events greatly added to the level of stress in the family's life.

15 - 16



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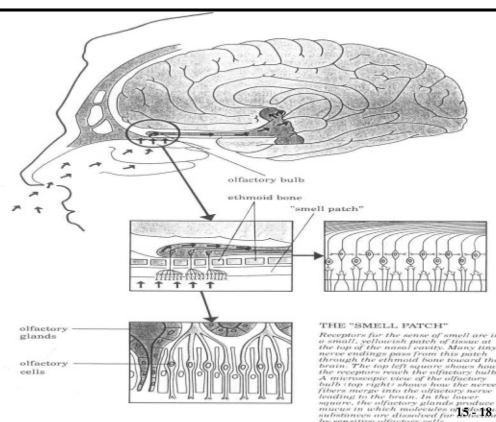

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Odors from Stationary and Mobile Sources 1979 National Academy of Sciences Study

It's purpose is to assist the Environmental Protection Agency in responding to the provisions of Section 403(b) of the 1977 Amendments to the Clean Air Act.

15 - 19

Odors from Stationary and Mobile Sources

COMMITTEE ON ODORS FROM STATIONARY AND MOBILE SOURCES
Board on Toxicology and Environmental Health Hazards
Assembly of Life Sciences
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1979

15 - 20

- **ODOR is: " A sensation of smell perceived as a result of olfactory stimulus"**
- **ODORANT is: "The substance which causes an odor"**

15 - 21

An Inspector is concerned with Odors so as to:

- **Identify them as a cause of public nuisance**
- **Identify the odorant**
- **Trace the source**
- **Collect evidence**
- **Determine if a regulation has been violated**
- **Assess the effectiveness of control**

15 - 22

Characteristics of Odor Perception

- **Olfactory sense becomes fatigued after continuous exposure**
- **Usually detected with significant change in quality or intensity**
- **Odors do not, of themselves, cause physical disease**
- **Ability to perceive odors varies from day to day**
- **Compounds of different constitution may yield similar odors**

15 - 23

Characteristics of Odor Perception

- **Unfamiliar odor is more likely to cause complaints than familiar one**
- **Perception of odor level decreases with increasing humidity**
- **Odor quality may change upon dilution**
- **Some persons can detect certain odor qualities but not others**

15 - 24

Odor Parameters or Dimensions

- **Detectability or Threshold**
- **Intensity**
- **Character**
- **Hedonic tone**

15 - 25

<u>Detectability or Threshold</u>

Refers to the theoretical minimum concentration of odorant stimulus necessary for detection in some specified percentage of the population.

15 - 26

The two types of thresholds that are evaluated are: the detection threshold and the recognition threshold

15 - 27

CHEMICAL	ODOR THRESHOLD	DESCRIPTION
ACETONE	100.0	CHEMICAL
ACROLIEN	0.21	BURNT, PUNGENT
TRIMETHYLAMINE	0.00021	FISHY
AMMONIA	46.8	BARN-LIKE
BENZENE	4.68	SOLVENT
HYDROGEN SULFIDE	0.00047	ROTTEN EGG
DIMETHYLAMINE	0.5	FISHY

<u>Odor Intensity</u>

Refers to the perceived strength of the odor sensation and increases as a function of concentration

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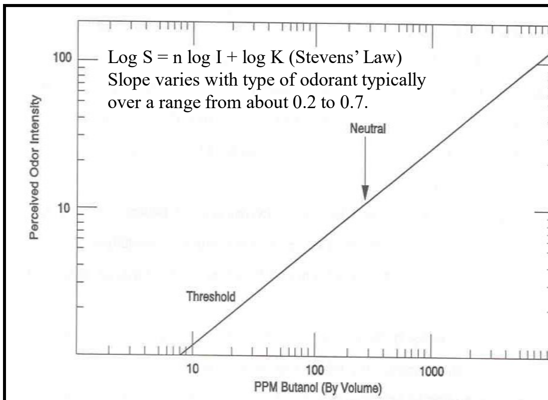


Odor intensity function for 1-butanol

15 - 30

Pervasiveness

The Tendency to Resist Being Dissipated by Dilution

15 - 31

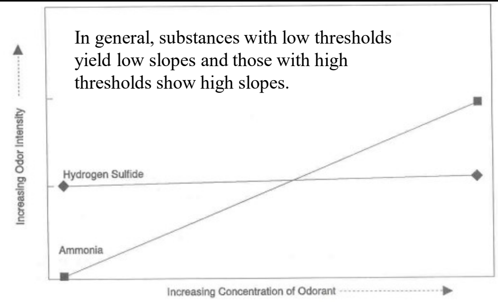


Figure 1-2. Relative slopes of psychophysical functions for ammonia and hydrogen sulfide. The schematic diagram depicts the steep odor intensity/concentration slope for ammonia as compared to the shallow slope for hydrogen sulfide. The difference in slopes means that at high concentrations of both odorants, the predominant odor will be that of ammonia, while at lower concentrations hydrogen sulfide will be detected.

15 - 32

Odor Character

What a substance smells like.

Typically rated on a scale of 0 to 5. Descriptors include fishy, hay, nutty, creosote, turpentine, rancid, sewer, and ammonia.

15 - 33

Odor Acceptability
Hedonic Basis (Like-Dislike)

The 9-Point Hedonic Scale

- Like Extremely
- Like Very Much
- Like Moderately
- Like Slightly
- Neither Like nor Dislike
- Dislike Slightly
- Dislike Moderately
- Dislike Very Much
- Dislike Extremely

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

15 - 34

NUMERICAL INDICATION OF ODOR STRENGTH

ODOR RATING	DESCRIPTION
0	NO DETECTABLE ODOR
1	ODOR BARELY DETECTABLE
2	ODOR DISTINCT & DEFINITE
3	ODOR STRONG
4	ODOR OVERPOWERING

15 - 35

Odor Rating System

- **No odor**
- **Very faint**
- **Faint**
- **Easily noticeable**
- **Strong**
- **Very strong**

15 - 36

Determinants of Odor Perception

- **Identity of odorant(s)**
- **Concentration(s) of odor(s)**
- **Ambient conditions**
- **Status of observer**

15 - 37

COMPLAINT	IDENTIFICATION
ROTTEN EGGS	H_2S
ROTTEN CABBAGE	MERCAPTAN
NATURAL GAS	MERCAPTAN
DEAD FISH	DI METHYLAMINE
OUTHOUSE	AMINES
ROTTEN ODOR	RENDERING
SCORCHED POPCORN	GRAIN DRYING BY DIRECT FLAME
COFFEE	COFFEE ROASTING
BLEACH	CHLORINE
AMMONIA	AMMONIA
PHENOL	PHENOL

15 - 38

Measurement of Odor Intensity

15 - 39

Forced-Choice Triangle Olfactometer: Lab Method

In this method, one diluted odor sample and two non-odorous air blanks are presented dynamically at each dilution level.

15 - 40

15 - 41

Odor Panels

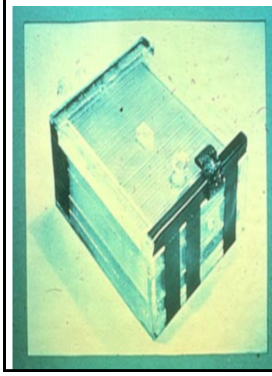
A panel of 9 or 10 is about the smallest, inasmuch as data obtained with smaller panels cannot be statistically tested with sufficient resolution of probabilities. Larger panels, 15-100 are needed for hedonic judgments.

15 - 42

Field Instruments for Odors

15 - 43

SCENTOMETER AS A FIELD INSTRUMENT



15 - 44

Use of a Scenometer at a Combination Extraction Well

15 - 45

Nasal Ranger as a Field Instrument

15 - 46

Responsible for Odors

- Interview complainants regarding intensity, evidence, and source of contaminant
- Identify contaminant causing the nuisance
- Track contaminant to its source or sources
- Inspect equipment at source to determine capacity to emit
- If appropriate, serve NOV or motivate remedy to situation
- If appropriate, collect signed affidavits from complainants

15 - 47

Odor Transport Characteristics

- Odor flows downwind from source to receptor
- Transport from vent or chimney is in a plume
- Transport with little dilution occurs during evening hours
- In unfavorable meteorology, odors can travel long distances
- Odors quality may change from source to receptor
- Odors leave no residual effects

15 - 48

Applicable Air Laws & Regulations

Illinois Environmental Act

Sec. 9. Acts prohibited. No person shall:
(a) Cause or threaten or allow the discharge or emission of any contaminant into the environment in any State so as to cause or tend to cause air pollution in Illinois, either alone or in combination with contaminants from other sources, or so as to violate regulations or standards adopted by the Board under this Act;

15 - 49

Complaints Of Noxious Odors Trigger Violation For Washtenaw County Landfill

Updated: Oct. 26, 2023, 9:02 a.m. | Published: Oct. 26, 2023, 9:01 a.m.

Arbor Hills Landfill, 10690 Six Mile Road in Salem Township on Tuesday, June 27, 2023. Jacob Hamilton | MLive.com

Complaints of noxious odors trigger violation for Washtenaw County landfill - mlive.com 15 - 50

NEWS

Arbor Hills landfill operators agree to $2.3 million lawsuit settlement for odor violations

Ed Wright
Hometownlife.com

Published 1:37 p.m. ET March 11, 2022 | Updated 1:39 p.m. ET March 11, 2022

Arbor Hills landfill at Six Mile and Napier. *John Heider/hometownlife.com*

15 - 51

Arbor Hills landfill, Michigan attorney general settle odor lawsuit (hometownlife.com)

Federal Landfill Air Regulations

<u>MSW Landfills NESHAP and NSPS/EG</u>

40 CFR Part 63, Subpart AAAA

40 CFR Part 60 Subpart XXX, WWW, C_e or C_f

40 CFR Part 62 Subpart OOO

15 - 52

Purpose of NSPS/EG Regulation

- Limit LFG migration subsurface off site
- Limit LFG migration into onsite structures
- **Limit LFG odors at or beyond the landfill boundary**
- **Limit LFG emissions into the atmosphere**

15 - 53

Ohio-Regulations Addressing Odors

- Source has to be subject to regulation under Ohio’s particulate matter, sulfur dioxide, carbon monoxide, photochemically reactive material, hydrocarbon, or permitting rules.
- Operated in such a manner to emit such amounts of odor as to endanger the health, safety, or welfare of the public, or cause unreasonable injury or damage to property.

15 - 54

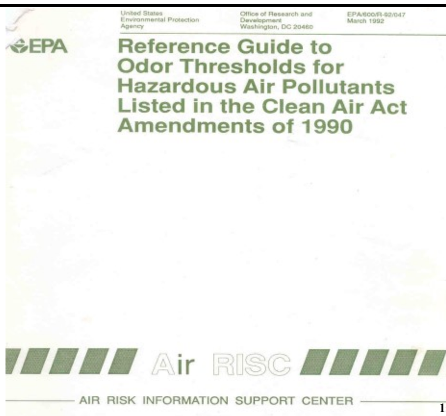
Resolution of the Nuisance

- Solution may require:
  - Eliminate odor problem ASAP
  - Improved maintenance program for GCCS
  - Modifying the operation
  - Relocation of equipment
  - Replacement of equipment
  - Installation of control devices or with better destruction efficiency
  - Involvement of community to discuss issues

15 - 55

Other Information

15 - 56



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TCEQ Toxicology Position Papers and White Papers

Toxicology Position Papers and White Papers

A compilation of papers written by the TCEQ Toxicology Division.

POSITION PAPER:

Approaches to Derive Odor-Based Values

This position paper was included as Section 2.2 of the 2015 updated RG-442 .

The Texas Commission on Environmental Quality revised Section 2.2, Odor-Based ESLs, of Guidelines to Develop Toxicity Factors (publication RG-442) (TCEQ 2012). This position paper was developed to describe how TCEQ toxicologists (1) evaluate available chemical-specific data for chemicals proposed for derivation, and (2) conduct analysis to determine whether development of an odor-based value is needed to prevent odor nuisance conditions. The TCEQ sought public comments on this position paper and a proposed odor ESL list and received several comments. The response to public comments addresses comments received on both of these documents. The list of odor values represents the substances that the TCEQ has determined have a need for an odor value (i.e., these substances are a product of following the position paper.

Please query the Toxicity Factor Database to search for toxicity factors (including AMCVs and ESLs) to see which value is to be used for permitting purposes (i.e., odor or short-term health).

WHITE PAPERS:

- TCEQ Guidelines for Systematic Review and Evidence Integration
- TCEQ Guidelines to Develop 24-Hour Inhalation Reference Values
- Updated Recommendations for Animal-to-Human Inhalation Dosimetry

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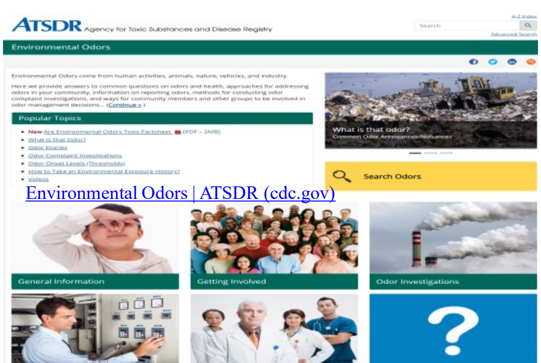
Toxicology Position Papers and White Papers - Texas Commission on Environmental Quality - www.tceq.texas.gov

ATSDR Environmental Odor Web site



Environmental Odors | ATSDR (cdc.gov)

Chemical Odor Threshold Web site

Sense of Smell Unit (nih.gov)

15 - 60

Inspections at MSW Landfills

Some of the Original Content is from USEPA Telecourse APTI T – 021-01 "The Use of Federal Reference Methods in the Evaluation of Landfill Gas Emissions" by William T. "Jerry" Winberry, Jr. EnviroTech Solutions (Retired)

16 - 1

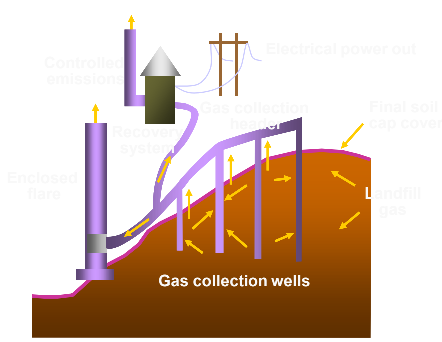
Inspections at MSW Landfills

16 - 2

16 - 3

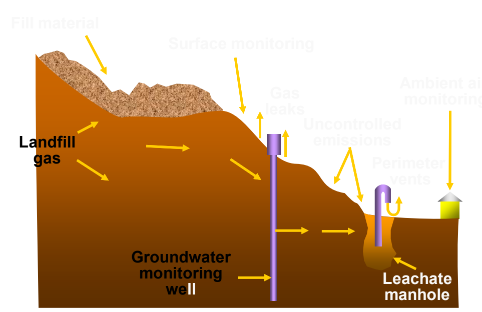
16 - 4

Landfill Gas Collection System Components



16 - 5

Landfill Gas Collection System Components



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Reasons for Inspections of MSW Landfills

- Compliance determination
- Complaint investigation
- Source plan approval
- Review or renewal of permits
- Special studies

16 - 7

Pre-Inspection General Guidelines

- ✓ **File review**
- ✓ **Regulation review**
- ✓ **Equipment check**
- ✓ **Pre-entry and entry**
- ✓ **Pre-inspection meeting**
- ✓ **Permit check**

8

File Review

- Initial design capacity report
- Annual or 5-year NMOC emission rate report
- Permit to construct (P/C) and permit to operate (P/O)
- Collection and control system design plan
- Equipment Source Test reports

16 - 9

File Review

- Annual reports
- Landfill closure reports
- Control equipment removal reports
- Previous inspection reports
- Enforcement action: Complaints and notice of violation

16 - 10

File Review

- Enforcement action taken, orders of abatement, variance history
- Compliance test data
- Equipment malfunction reports
- SSM Plan and any events

16 - 11

Regulation Review

- Identify all rules that apply to the facility
- Review any references to the specific rules which are noted in the landfill file
- Be familiar with each standard and exemption
- NESHAP Residual Risk and Technology Review (RRTR) March 26, 2020 for MSW Landfills

16 - 12

Equipment Check

- Hard hat
- Gloves
- Safety vest
- Respirator/dust mask
- Method 21 system route map
- Steel-toed safety shoes

16 - 13

Equipment Check Contd.:

- Safety glasses
- First aid kit
- Flashlight
- Field checklist
- Portable monitor (gas detector system)
- Digital manometer

16 - 14

Portable Monitor

- Obtain certified portable gas monitor
- Verify operating conditions and specifications
  - Assemble and start-up instrument according to manufacturer's instructions
  - Leak check sampling system
  - Charge batteries the day before

16 - 15

Portable Monitor Cont.:

- Evaluate response factor (RF) with known concentration of certified methane gas
- Evaluate calibration precision with certified methane gas standard using zero gas or background as low calibration point
- Repeat two additional times

16 - 16

Portable Monitor Contd.:

- Calculate calibration precision
- Check response time during calibration precision evaluation
- Verify sample flow rate

16 - 17

16 - 18

Notify the Landfill

- Notify landfill of inspection so that relevant documents can be made available for review
- Obtain map and/or diagram of the landfill with elevations, wellhead locations, header system placement and control devices.

16 - 19

Pre-entry

- Look at landfill from neighborhood
- Take wide angle picture of landfill for file
- Talk to neighbors about activities at landfill if there is a complaint

16 - 20

16 - 21

Pre-entry

- Where possible, drive around the outside perimeter of the landfill
  - Notice any landfill odors?
  - See any visible emissions?
  - Litter in neighborhood which looks like it originated from the landfill?

16 - 22

Entry

- Enter by public access route
- Identify yourself, present your credentials
- Ask to meet with the site representative

Pre-Inspection Meeting

- Explain purpose of inspection and discuss any new rule changes
- Answer questions that the source personnel may have
- Identify equipment to be used in the inspection (FID, PID, FLIR camera, etc

16 - 24

Pre-Inspection Meeting Information

- Verify facility information
  - Facility name, ownership
  - Facility address, telephone number
  - Facility contact name, telephone number
- Discuss safety procedures

16 - 25

Pre-Inspection Meeting Information

- Review Permit
  - Verify
    - that permit is current and posted
    - that permit is for correct equipment
    - that permit operating conditions are being met
    - date permit issued
    - design capacity information

16 - 26

Pre-Inspection Meeting

- Review permit specification from office to on-site
  - List of equipment/wellheads installed or to be installed
  - Emission limits to be met
  - Changes/modifications to permit conditions
  - Site-specific monitoring requirements

16 - 27

Pre-Inspection Meeting

- Operational Logs
  - Historical emission records and self monitoring data available from past 5-years
  - Monitoring and calibration logbooks

16 - 28

Pre-Inspection Meeting

- Operational logs for active collection systems
  - Logbooks associated with well head monthly monitoring parameters:
    - Temperature
    - Gauge pressure
    - Gas concentrations of:
      - Oxygen
      - Nitrogen

      - There should also be information in the Agency files, in regards to this information

16 - 29

Pre-Inspection Meeting

- LFG control system operational logs for flares, co-generation facilities, gas turbines, or internal combustion engines
  - Calibration, operation, and maintenance records
  - Equipment "downtime"

16 - 30

Pre-Inspection Meeting

- Heat sensor operational records
- Continuous temperature recordings
- Compliance testing performed since last inspection
- LFG monthly gas flow rate
- Well concentration readings

16 - 31

Pre-Inspection Meeting

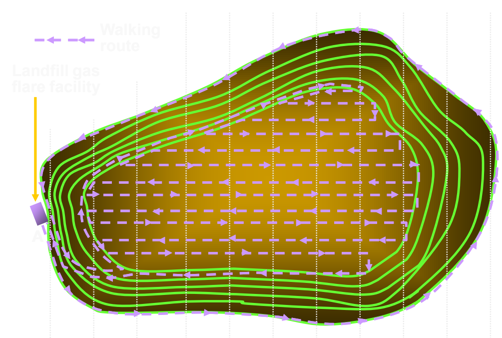
- Environmental Data
  - Average wind speed for today (< 10 mph)
  - Rain fall over last seven days (Weather Underground)
  - Barometric pressure over last seven days

16 - 32

Pre-Inspection Meeting

- Sampling Grid Pattern
  - Obtain from pre-inspection or create a sampling grid pattern over a map of the landfill, with parallel lines approximately 30 meters apart
  - Start grid pattern at control device, then around perimeter of landfill, then into landfill with parallel lines

16 - 33

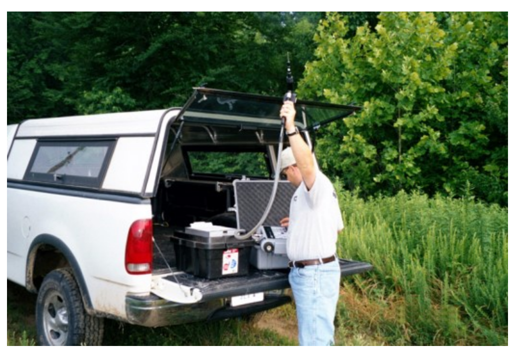


16 - 34

Physical Inspection of Landfill

- Start the on-site physical inspection of the landfill at the outer perimeter
- Acquire a "background/upwind" concentration of LFG using FRM 21 certified monitor

16 - 35



16 - 36

Physical Inspection of Landfill

- Observe visible emissions (VE)
  - Haul road, flares, energy recovery systems
- Continue to control equipment and follow the grid pattern

16 - 37

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Physical Inspection of Landfill

- Collection and control equipment, note
  - Comparison between landfill records and visual inspection
  - Observation of Leaks and maintenance
  - Operations according to site-specific collection system design plan

16 - 39

Physical Inspection of Landfill

- Monitor surface of landfill with FRM 21 gas monitoring probe
  - Position FRM 21 monitor with tip approximately 2-4 inches off ground
  - Follow the grid route around perimeter of site, noting a reading every 30 meters. Record readings on field test data sheet (FTDS)

16 - 40

16 - 41

Physical Inspection of Landfill

- Enter the site according to the grid route map
- Take readings every 30 meters, until the complete landfill surface has been evaluated, using the grid route
- Any reading 500 ppm above background should be recorded on FTDS and marked with a flag

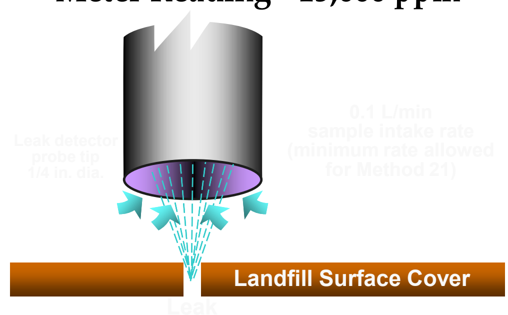
16 - 42

Physical Inspection of Landfill

- Monitoring surface of landfill
  - Monitor any crack, hole, breach in the surface, and interface with undisturbed native soil
  - Monitor around rocks and objects sticking out of the surface of the landfill for possible LFG emissions

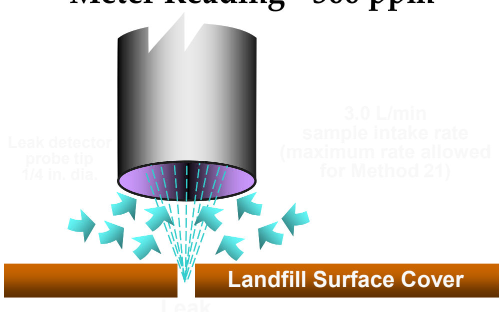
16 - 43

Meter Reading - 15,000 ppm



16 - 44

Meter Reading - 500 ppm



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Monitoring LFG Collection System

- As you monitor the landfill, note
  - Any leaks heard coming from the LFG collection system
  - Any broken header lines
  - Any well heads broken and venting LFG

16 - 50

Monitoring LFG Collection System

- Elevated concentrations of LFG:
  - Around horizontal or vertical well casings
  - Venting from LFG well vaults
  - Around connecting tubing etc.

16 - 51

Monitoring LFG Collection System

- Monitor extraction well parameters and compare to pre-inspection values
  - Temperature
  - Static pressure
  - Gas concentrations
    - Oxygen and Nitrogen

16 - 52

Monitoring Perimeter Gas Probes

- Monitor perimeter gas probes and compare to historical data
- Monitor perimeter water monitoring wells and compare to historical data acquired in pre-inspection meeting

16 - 53

Monitoring Selected Wellheads (Records)

- Temperature
- Gauge pressure
- Gas composition (O_2, CH_4, CO_2, N_2, etc. in %)

How to use a Landtec GEM 5000 - YouTube

16 - 54

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Post-Inspection Procedures

- Perform single point calibration of FRM 21 gas monitoring system
- Compile field data sheets and observation notes

16 - 60

Post-Inspection Meeting

- Discuss deficiencies and inform owner of inspection results
- Advise source representative of any additional concerns that you might have
- Discuss corrective action to be taken for identified leaks

16 - 61

Example Format for Inspection Documentation/Report

- Prepare
  - A written description of the landfill
  - A diagram showing the location of control equipment, emission points, and tagging of any emission exceedances

16 - 62

Example Format for Inspection Documentation/Report

- A statement indicating compliance or violation for each emission point recorded
- Recommendations, if any, such as a source test or an engineering evaluation
- Assessment of fugitive emissions and other potential impacts

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Safety

- ✓ Hard hat
- ✓ Eye protection
- ✓ Hearing protection
- ✓ Safety boots
- ✓ Monitoring device
- ✓ Safety vest

16 - 65

Use of the FLIR Camera and Other Devices for Monitoring Landfill Gases

17 - 1

GasFindIR Camera Operation


17 - 2

Gas Imaging Cameras

- Image example (visible vs. infrared image)
- Digital video connection, USB, and a direct connection to charge the battery inside the camera
- Contrast, polarity and brightness adjustments
- High sensitivity mode
- Alternate work practice
- Integrated visual camera
- Cost: ~$102,000 with telephoto and standard lens

17 - 3

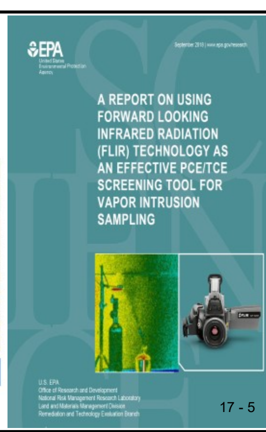
GasFindIR Camera with Digital Recorder (Older Model)

17 - 4

EPA Handbook: Optical and Remote Sensing for Measurement and Monitoring of Emissions Flux of Gases and Particulate Matter

9/1/2018 Informational Document

This informational document describes the emerging technologies that can measure and/or identify pollutants using state of the science techniques

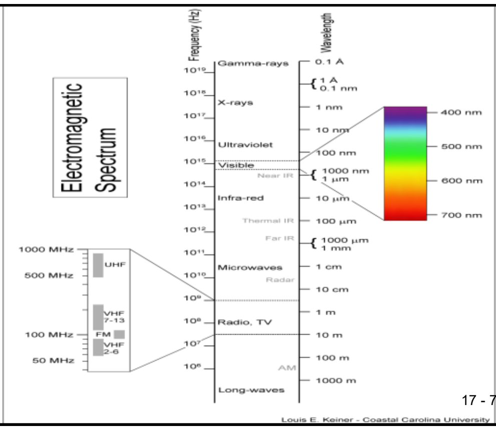


17 - 5

Camera Operation

- **GasFindIR is battery powered and is cooled to 77 °K by liquid helium via a closed-cycle cooler powered with a small compressor. The cooling makes the detector more sensitive to thermal energy at low temperatures.**

17 - 6



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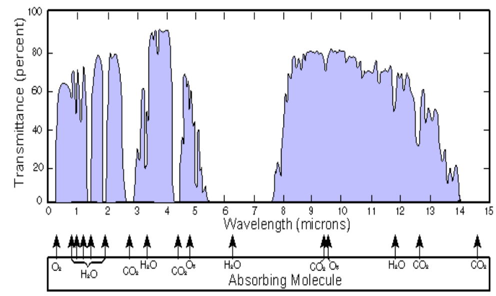
Atmospheric Transmittance



17 - 8

Infrared Camera Detection

- **GasFindIR uses a spectral filter tuned to a narrow width of about 200 nm and operates in the 3 – 5 µm atmospheric midwave waveband.**
  Camera detection is between 3.3 – 3.4 µm; the region in which hydrocarbon gases absorb thermal energy.
  Other Infrared Cameras operate in the Longwave band of about 8 – 12 µm and
  Optical Cameras operate in the Visible wavelength which is 0.4 – 0.75 µm

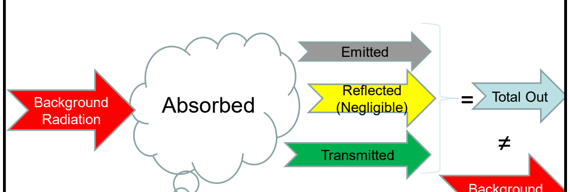
17 - 9

Principles of Gas Detection

- To detect a gas cloud, there needs to be a radiation contrast between the cloud and the background. The apparent temperature of the gas cloud needs to be different than the background temperature.

17 - 10

Radiation Energy and The Gas Plumes



For the Infrared camera to see the gas vapors there must be a radiation contrast between the gas and the background

17 - 11

December 22, 2008 FR and 40 CFR §60.18

- On April 6, 2006, USEPA proposed a voluntary alternative work practice for leak detection and repair using a newly developed technology, optical gas imaging.
- The proposed alternative was amended in the final rule on December 22, 2008 to add a requirement to perform monitoring once per year using the current Method 21 leak detection instrument. This action revises the General Provisions to incorporate the final alternative work practice.
- 40 CFR §60.18 General Control Device And Work Practice Requirements.

17 - 12

Alternative Work Practice

- The Alternative Work Practice allows owners or operators to identify leaking equipment using an optical gas imaging instrument instead of a leak monitor prescribed in 40 CFR part 60, Appendix A–7 *i.e., a Method 21 instrument.*

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Source Applicability Criteria

- The applicability criteria to examine is found in 40 CFR parts 60, 61, 63, and 65, including, but not limited to: Part 60, subparts A, Kb, VV, XX, DDD, GGG, KKK, QQQ, and WWW; part 61, subparts A, F, L, V, BB, and FF; part 63, subparts A, G, H, I, R, S, U, Y, CC, DD, EE, GG, HH, OO, PP, QQ, SS, TT, UU, VV, YY, GGG, HHH, III, JJJ, MMM, OOO, VVV, FFFF, and GGGGG; and part 65, subparts A, F, and G. (Essentially where method 21 is required to be used)

17 - 14

Uses of Optical Gas Imaging for Other Types of Sources

- **Sour Crude Tank Battery Emissions (VOC's)**
- **Sour Crude Brine and Oil Separator Lagoons (VOC's)**
- **Landfill Gas Wellhead Emissions (Methane)**
- **Gasoline Dispensing Facility fugitive Emissions (VOC's)**
- **Oil Re-refiner tank storage vent Emissions (VOC's)**
- **Chemical Mixers fugitive emissions**
- **Storage tank VOC emissions from seals and vents**
- **Fracking facilities**

17 - 15

Gas Imaging Cameras: Thermal IR Cameras

Vendors

FLIR, Inc.	www.flir.com
Gas Imaging Technology, LLC	http://www.gitint.com/
Leak Surveys, Inc.	www.leaksurveys.com

Gaseous Compounds that can be Detected by Thermal IR Cameras	
Acetic Acid	Isoprene
Anhydrous Ammonia	Methane
Benzene	Methanol
Butane	MEK
Carbon Monoxide	MIBK
Chlorine Dioxide	Nitrous Oxide
Dichlorodifluoromethane	Octane
Ethane	Pentane
Ethanol	1-Pentene
Ethylbenzene	Propane
Ethyl Cyanoacrylate	Propylene
Ethylene	Sulfur Hexafluoride
Heptane	Toluene
Hexane	Xylene

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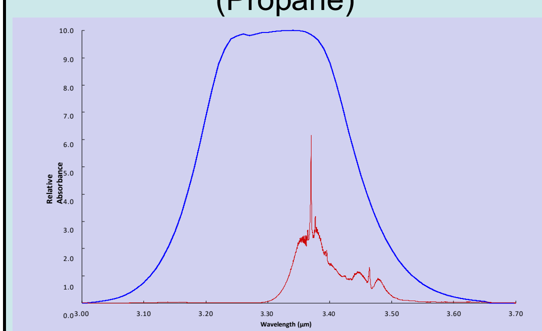
Infrared Camera Target Gas Sensitivities

Gas	Absorbtion Coefficient	Relative to Propane
Hexane	0.057	1.61
Pentane	0.051	1.43
MTBE	0.045	1.25
Propane	0.036	1.00
M-xylene	0.027	0.76
Ethanol	0.019	0.53
Benzene	0.013	0.36
1,3-butadiene	0.009	0.26
Formaldehyde	0.007	0.18
Ethylene	0.006	0.17
Vinyl Chloride	0.001	0.03
Water Vapor	0.000	0.00

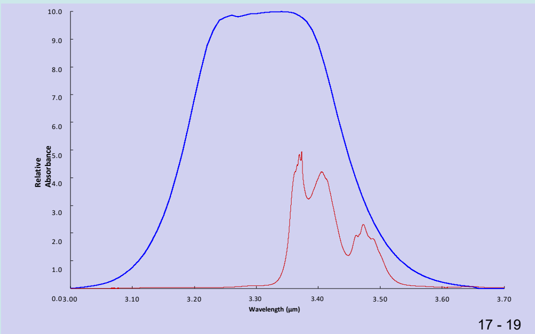
17 - 17

Research Results: Example Spectra (Propane)



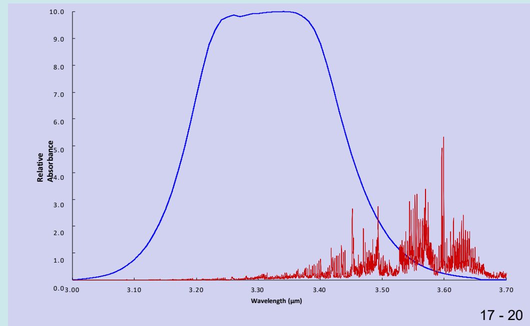
17 - 18

Research Results: Example Spectra (Hexane)



17 - 19

Research Results: Example Spectra (Formaldehyde)



17 - 20

Primary Characteristics

- LFG approx. 50% methane
- Methane is combustible/ explosive gas
- Lower explosive limit (LEL) = 5% CH4
  Lower – not explosive in air
- Upper explosive limit (UEL) = 15% CH4
  >15 %, too rich to be explosive in air
- Heat content of Gas from landfills
  Approx. 500 Btu/cu ft as compared to:
  Natural gas which is almost entirely CH4 has about 1,000 Btu/cu ft

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(CONTINUED)

Compound	VOC[a]	Hazardous Air Pollutant[b] (HAP)
Dichlorobenzene[d]	Y	Y
Dichlorodifluoromethane	N	N
Dichlorofluoromethane	N	N
Dichloromethane (methylene chloride)	N	Y
Dimethyl sulfide (methyl sulfide)	Y	N
Ethane	N	N
Ethanol	Y	N
Ethyl mercaptan (ethanethiol)	Y	N
Ethylbenzene	Y	Y
Ethylene dibromide	Y	Y
Fluorotrichloromethane	N	N
Hexane	Y	Y
Hydrogen sulfide	N	N
Mercury[e]	N	Y
Methyl ethyl ketone	Y	Y
Methyl isobutyl ketone	Y	Y
Methyl mercaptan	Y	N
Pentane	Y	N
Perchloroethylene (tetrachloroethylene)	N	Y
Propane	Y	N

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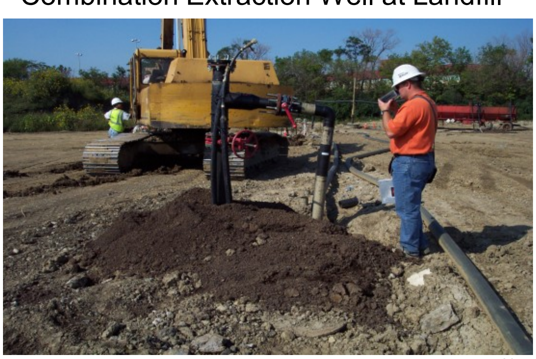
Combination Extraction Well at Landfill



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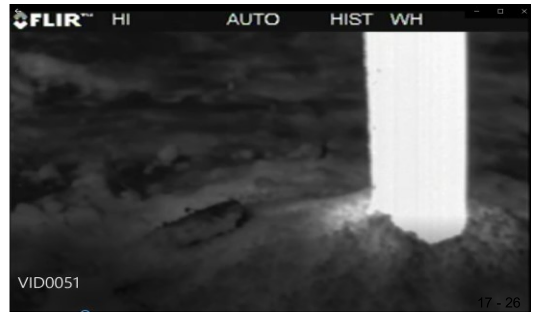
Landfill Vertical Gas Extraction Well

17 - 24

Vertical Landfill Gas Extraction Well

17 - 25

Vertical Wellhead Area Fugitive Emissions



17 - 26

Leachate Extraction Well Riser

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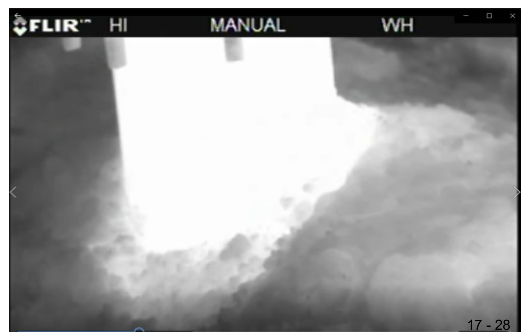
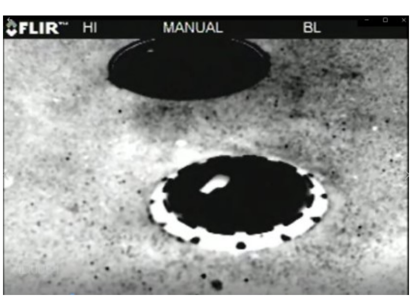
Leachate Extraction Well Riser Fugitive Emissions



17 - 28

Fill pipe area for underground storage tank



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Advice and Tips for GasFindIR Use

- **Determine absorption band of gas to be detected (NIST web site)(see next slide).**
- **Charge batteries and Digital Recorder the day prior to site visit.**
- **Have at least 2 inspectors for the inspection.**
- **Cloudy days or evenings are best (Cannot Always Predict).**
- **Scan slowly in manual mode and switch polarity while scanning object area; switch to color viewing if you think it would be helpful.**
- **Take digital pictures or standard videos in addition to GasFinder videos.**
- **Bring an FID or PID for additional detection capability.**

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National Institute of Standards and Technology (NIST)

http://webbook.nist.gov/

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Further Reading

Chemical Engineering Progress Article
"A Smarter Way to Detect Fugitive Emissions"; December 2007
Article discusses GasFindIR technology, minimum detectable leak rates with wind speeds and other types of instruments for fugitive emissions

http://en.wikipedia.org/wiki/Thermography

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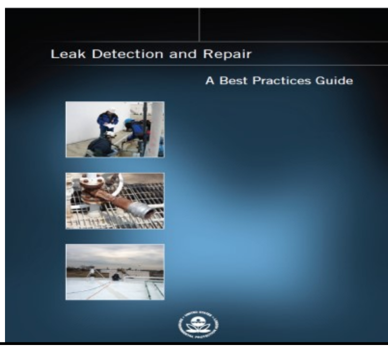
http://www2.epa.gov/sites/production/files/2014-02/documents/ldarguide.pdf



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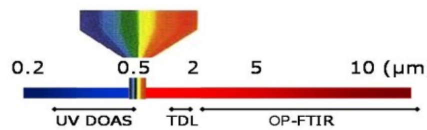
Open Path Technologies



Open-path technologies measure the average concentration of chemicals or particulates across an open path of air or line of sight. They do this by emitting a concentrated beam of electromagnetic energy into the air and measuring its interactions with the air's components.

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UV DOAS

Approximate Detection Limits for UV-DOAS Pollutant	Lower Detection Limit (ppb)	Path Length (m)
Ammonia	4	150
Benzene	single digit ppb	500
Carbon Disulfide	5	250
Formaldehyde	single digit ppb	500
Nitrous Acid	single digit ppb	500
Nitrogen Dioxide	single digit ppb	1000
Nitrogen Oxide	10	150
Ozone	single digit ppb	1000
Sulfur Dioxide	single digit ppb	1000
Toluene	single digit ppb	200
m,p-Xylene	10	500
o-Xylene	20 ppb	500

UV-DOAS Vendors	Websites
Argos Scientific	www.argos-sci.com
Environnement S.A. Sanoa UV/Visable DOAS	www.environnement-sa.com
ETG Risorse e Tecnologia	www.etgrisorse.com
IMACC	www.ftirs.com
Opsis, Inc.	www.opsis.se
Spectrex	www.spectrex-inc.com
Cerex Monitoring Solutions	www.cerexms.com

Can also measure 1,3-Butadiene with low- range IR detector (Opsis AR600), Acrolein, Chlorine, Ethyl Benzene, Hydrogen Fluoride, Styrene, Isoprene and Mercury

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UV DOAS

UV-DOAS Strengths
•Automated: Real- time measurements up to 24/7 continuous remote data
•Economical: Relatively low instrument cost (about $60,000 - $200,000)
•Low-cost long term deployment
•Multiple Wavelength Operation: Monitoring of three species simultaneously.
•Spectra can be saved and post analyzed
•Long measurement path length – up to 500 m. Many compounds are detectable in the low ppb range

UV-DOAS Limitations
•Meteorological Limitations: Fixed observation area (winds). Affected by poor visibility conditions.
•Limited Compounds: A number of species are undetectable by UV-DOAS
•Application Limitations: Some models have difficulty aligning optics from multiple paths and long path lengths, making radial plume mapping more difficult (the Opsis 130 telescope has overcome this, it can move).

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UV DOAS Applications

- Chlor Alkali Study: Olin Corporation in Augusta Georgia: Used UV-DOAS in 2000 to measure mercury emissions from a Chlor- Alkali plant (produces chlorine gas and sodium hydroxide by electrolysis using a mercury cathode).
- Westlake Petrochemicals: Under a consent decree, a UV-DOAS system is being used for fence-line monitoring at the facility in Westlake, Louisiana. The data generated from this system, which is measuring primarily monoaromatics are made available to the public on an Internet webpage. A special condition of the decree requires the company to provide data to any nearby resident requesting it by the next business day following the request.
- Cary Secrest, UV DOAS Expert, EPA OCE

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FTIR Open Path

Can detect more than a hundred compounds, including:
Acetylaldehyde,
Acrolein,
Acrylonitrile
Ammonia,
Benzene,
1,3-Butadiene Carbonyl Sulfide
Halogenated Hydrocarbons
Formaldehyde,
Hydrogen Chloride,
Hydrogen Cyanide, Hydrogen Sulfide, MEK
Styrene, Sulfur Dioxide, Toluene
Vinyl Chloride,
Xylenes

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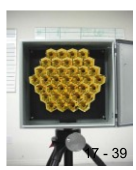
Open Path FTIR

OP-FTIR's Strengths

- **Economical: Relatively low instrument cost (about $80,000 - $125,000). Low-cost long term deployment**
- **Equipment is fairly rugged and easily portable**
- **There are a large number of compounds that are infrared active (absorb IR light)**
- **Large number of compounds can be analyzed simultaneously.**
- **Spectra can be saved and post analyzed**
- **No gas calibration standards necessary for field testing (uses standard reference spectral library), needed for laboratory confirmation of instrument performance and calibration.**
- **Automated Real-time Measurements: Equipment can be allowed to run with minimal attention for months at a time with remote access to check instrument operation, schedule cryogen replenishment and recover data.**
- **No sample collection, handling, or preparation is necessary**

Vendors OP-FTIR Instruments	
KASSAY FSI – *Ail Systems Inc.	www.kassay.com
*Spectrex, Inc.	http://www.spectrex-inc.com
IMACC Instruments	http://www.ftirs.com/
MIDAC Corporation	http://www.midac.com/
ruker Optics	http://www.brukeroptics.com/opag.html
ABB/Bomem	http://www.abb.com/analytical



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*Verified by EPA's Environmental Technology Verification Program

Open Path FTIR

OP-FTIR's Limitations
Spectral Interferences: Gas-phase water, CO and CO2 spectral interference.
Diatomoic Molecules: Not applicable to homonuclear diatomic gases such as chlorine, oxygen, and nitrogen
IR Wavelength Range and Interferences: Because of weak IR absorption features for many molecules, interferences and limited IR beam range, may not be sensitive enough to meet ambient data quality objectives for many species
Path Length Range: Maximum path length is on the order of 400–500 meters
Field Implementation Requirements: Typical infrared detectors require cryogenic cooling to operate, liquid nitrogen used for detector cooling must be refilled and maintained regularly (weekly), field implementation and data collection requires highly experienced personnel
Setup Time Consuming and Costly: Typical set-up time usually requires about 5 to 8 hours and a minimum of two people, if multiple vertical or horizontal path measurements are necessary, can require significant time and cost to set up and implement.
Measurement Limitations: Single beam open-path method measures concentration along a path. The path must capture most if not all of an analyte plume to provide accurate measure of emissions.

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FTIR Open Path Applications

- Texas Petrochemicals: Settlement agreement with City of Houston requires OP-FTIR monitoring at north and south fence lines for 1,3-butadiene.
- Houston Refining: Under Texas' Audit Privilege, used OP-FTIR to measure total hydrocarbon and benzene emissions from delayed coker unit.

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Tunable Diode Laser

OP-TDL Vendors	
Boreal Laser	www.boreal-laser.com
OPSIS AB	www.opsis.se
Leister Process Technologies, Axetris Division	www.ir-microsystems.com
Norsk Elektro Optikk (NEO, Norway)	www.neo.no
PKL Technologies, Inc.	www.pktechnologies.com
PSI Physical Sciences, Inc.	www.tdlas.com www.psicorp.com
Senscient	www.senscient.com
Simtronics group	www.simtronics.eu
Unisearch Associates, Inc. (Concord, Canada)	www.unisearch-associates.com

Gaseous Compounds Measured by OP-TDL Systems	**Approximate λ (nm)**	**Reported Detection Limit (ppm-m)**
ammonia	760, 1500	0.5-5.0
carbon monoxide	1570	40-1,000
carbon dioxide	1570	40-1,000
hydrogen chloride	1790	0.15-1
hydrogen cyanide	1540	1.0
hydrogen fluoride	1310	0.1-0.2
hydrogen sulfide	1570	20
methane	1650	0.5-1
nitric oxide	1800	30
nitrogen dioxide	680	0.2
oxygen	760	50
water	970, 1200, 1450	0.2-1.0
acetylene	1520	*
ethylene	1693	*
formaldehyde	1930	*
hydrogen bromide	1960	*
hydrogen iodide	1540	*
nitrous oxide	2260	*
phosphine	2150	*
propane	1400, 1500, 1700	*

*These compounds are not commonly measured; therefore detection limits are not readily available.

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Tunable Diode Laser

Tunable Diode Laser Strengths

- Minimal maintenance required and no consumables. Potential for remote access and control and user friendly
- High temporal resolution and real-time results
- Stable multi-pass optical cell: High sensitivity, longer effective path lengths, insensitive to vibrations
- Internal temperature and pressure controls: Minimal drift, frequent calibration unnecessary, immune to ambient relative humidity and temperature changes and laser intensity fluctuations
- No sample pre-conditioning or treatment required before analysis.
- Easy field deployment and installation, can use low power optical sources

Tunable Diode Laser Limitations

- Detects only one compound per laser, fewer measureable compounds, and limited sensitivity
- limited to compounds with overtone absorbences in the near- and mid-IR range
- Dust and objects can block the optical path

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Cavity Ring-Down Spectrometer

- Laser absorption spectrometry, measures optical extinction of compounds that scatter and absorb light in a closed sample path (longer effective sample path lengths for greater detection sensitivity)
- Good for measurements of weakly-absorbing or highly-dilute atmospheric samples
- Measures the rate of decay of light intensity exiting from an optical cavity rather than the change in light intensity
- Current application involves methane detection from oil and gas operations in the DFW region

Example list of CRDS detectable pollutants

Methane-52 ppbv Acetylene-4 ppbv TNT-0.075 ppbv
Chlorobenzenes-ppmv levels Ammonia-19 ppbv
Mercury-0.01 ppbv

Minimum detectable mixing ratio at 1σ noise level

CRDS Vendors	
Picarro, Inc. (CRDS)	www.picarro.com
Tiger Optics	www.tigeroptics.com
Los Gatos Research (ICOS)	www.lgrinc.com

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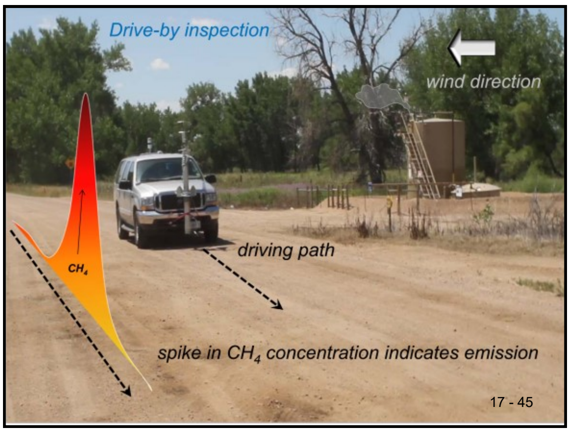


Cavity Ring-down Spectrometer

Air canister samples collected if methane is detected to determine other constituents. Soon, mini-UV DOAS instead.

Vertical transects collected along the length of plume to get average concentration

17 - 46

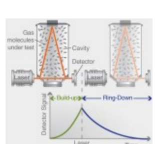
Cavity Ring-Down Spectrometer (CRDS)

CRDS Strengths

- Simple design: Minimal maintenance, no consumables, user friendly
- Fast detector: High temporal resolution and real-time results
- Stable optical cell: Insensitive to vibrations during measurements
- Internal temperature and pressure controls: Frequent calibration unnecessary, immune to ambient changes (such as relative humidity and temperature) and laser intensity fluctuations
- Direct sampling: No sample pre-conditioning or treatment required
- Compact and can use low power optical sources: Easy field deployment and installation

CRDS Limitations

- May need to apply sample filtering components to avoid interferences
- Lasers limitations: Only certain spectral ranges available
- Mirrors are only able to reflect over a small wavelength range (about ± 15%)
- Multiple species detection difficult
- High quality lasers and mirror: drive up the cost of the instrumentation



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Cavity Ring Down Monitoring At a Region 5 Landfill

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Differential **A**bsorption **L**ight Detection and Ranging (DIAL)

Species Measured by DIAL	Sensitivity (1)	Maximum Range (2)
Benzene	10 ppb	800 m
Sulfur Dioxide	10 ppb	3 km
Toluene	10 ppb	800 m
Ethane	20 ppb	800 m
Ethylene	10 ppb	800 m
Methane	50 ppb	1 km
General Hydrocarbons	40 ppb	800 m
Hydrogen Chloride	20 ppb	1 km
Methanol	200 ppb	500 m

(1) Concentration sensitivities from NPL for measurements of a 50 meter wide plume at a range of 200 meters, under typical meteorological conditions.
(2) The range value represents the typical working maximum range for the NPL DIAL system.

DIAL Strengths
- Provides spatially resolved pollutant concentration in two dimensions
- Measurements are provided in a relatively short period of time
- Deployable in many different applications and configurations, moveable
- Can measure long path lengths (1 to 3 km)

DIAL Limitations
- Due to limited availability, DIAL systems used in North America are typically imported, which increases the expense
- Chemical species that can be characterized are limited to those compounds with the unique chemical properties required to be detected
- Only a few wavelengths are measured (spectral artifacts cannot be fixed or investigated)

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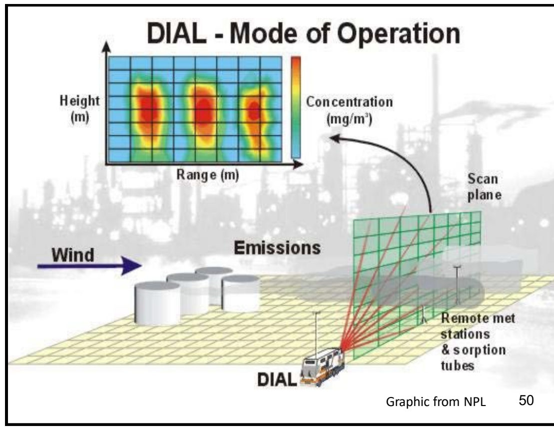

Graphic from NPL 50

DIAL Applications

- Tonawanda Coke: Coke oven site, July 2009 Test Order for Benzene Emissions, May 2010
- BP Texas City: Voluntary Study with TCEQ and EPA funding, Benzene and VOC emissions, July to August, 2007
- Shell Deer Park: Voluntary Study with EPA, Environment Canada and City of Houston funding, Benzene and VOC emissions, January to March, 2010

DIAL Vendors	
Spectrasyne	http://www.spectrasyne.ltd.uk/
LASEN	http://www.lasen.com/
National Physical Laboratory	http://www.npl.co.uk/
ITT	http://www.itt.com/

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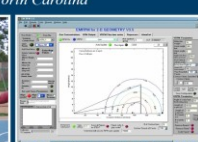
EPA United States Environmental Protection Agency

Innovative Air Monitoring at Landfills Using Optical Remote Sensing with Radial Plume Mapping

Susan Thorneloe, EPA/NRMRL
Thorneloe.Susan@epa.gov

Bruce Harris, EPA/NRMRL
Harris.Bruce@epa.gov

Research Triangle Park, North Carolina



1 **Office of Research and Development**
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division

February 22, 2007 17 - 52

Unmanned Aerial Vehicles

http://www.epa.gov/ttn/aimtc/files/2014conference/wedngambaxter.pdf

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- The National Air Toxics Assessment, U.S. Environmental Protection Agency, March 2011 http://www.epa.gov/nata2005/
- The Integrated Risk Information System, U.S. Environmental Protection Agency, http://cfpub.epa.gov/ncea/iris/index.cfm?fuseaction=iris.showSubstanceList
- Final Analytical TAGA Report, Urban Air Toxics Study in Harris County, U.S. Environmental Protection Agency, Emergency Response Team/Lockheed Martin, March 2007
- Marathon Petroleum Company, LP and Cattlets Refining, LLC Settlement Information Sheet, April 2012, http://www.epa.gov/compliance/resources/cases/civil/caa/marathonrefining.html

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- Tonawanda, NY DIAL Study Results, U.S. Environmental Protection Agency, Region 2, September 2010, http://www.epa.gov/region02/capp/TCC/tonawanda_docs.html
- Characterization of Mercury Emissions at a Chlor-Alkali Plant, U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, January 2002, http://www.epa.gov/region05/mercury/pdfs/Chloralkalireport.pdf
- Measurement of Total Site Mercury Emissions for a Chlor-Alkali Plant Using Open- Path UV-DOAS, U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, July 2007, http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1009COE.txt
- Other Test Method 10 (OTM 10) - Optical Remote Sensing for Emission Characterization from Non-Point Sources, U.S. Environmental Protection Agency, Technology Transfer network, Emissions Measurement Center, June 2006, http://www.epa.gov/ttn/emc/prelim/otm10.pdf

17 - 55

Use of the FRM 21 Analyzer for Surface Monitoring of Landfill Gases

18 - 1

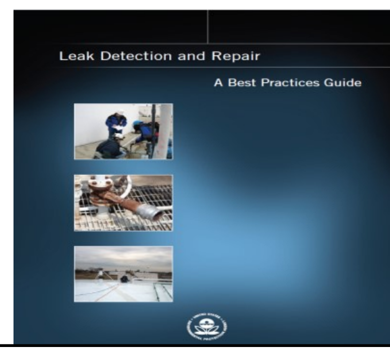
Landfill Vertical Gas Extraction Well

18 - 2

Vertical Landfill Gas Extraction Well

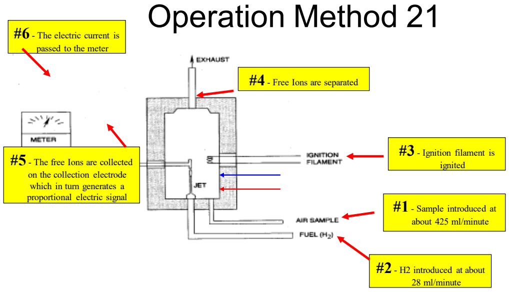
18 - 3

http://www2.epa.gov/sites/production/files/2014-02/documents/ldarguide.pdf



18 - 4

FID – Flame Ionization Detector Operation Method 21



18 - 5

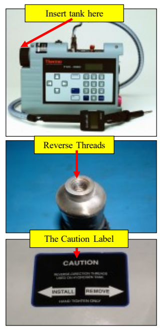
FID (TVA-1000B Specifications)

- Dynamic Range 0 to 50,000 ppm
- Linear range 0 to 10,000 ppm
- Response time < 3.5 seconds
- Low detection level *300 ppb hexane*
- Repeatable *+/- 2%*
- Fuel 99.99 % H_2
- Unaffected by ambient levels of CO, CO2 and water vapor

18 - 6

The Hydrogen Delivery System

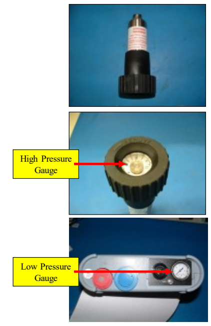
- An 85 cc tank is supplier with TVA and is used to hold the Hydrogen that operates the FID.
- The tank is inserted in the round opening on the left side of the TVA.
- The tank has reversed threads
- Caution label tells how to install & remove the tank.
- Only tighten until you feel slight resistance. Over tightening may damage the threads on either the tank, the instrument's fitting or both. **



18 - 7

The Hydrogen Tank

- Fill with no more than 2200 lbs. Of Hydrogen
- Always bleed the H2 tank empty before shipping the TVA.
- Always remove the H2 tank from the instrument when transporting the TVA.
- The high pressure gauge tells how many pounds of H2 remain in the tank.
- The low pressure gauge shows that the H2 is flowing through the TVA once the H2 shutoff valve is opened. **



18 - 8

Multiple Probe Options

- Basic Probe displays measurement data.
- 4 line by 20 character LCD display.

- Enhanced Probe Enhanced Probe
- T8 Line x 20 character LCD display.

<u>NEVER plug the probe in with the TVA on.</u>

18 - 9

Calibration

- Basic calibration steps
  - Fill hydrogen tank
  - Turn on and run for 20 minutes (best stability)
  - Zero both detectors (if dual unit)
  - Introduce calibration gases
    - FID – methane
    - PID – isobutylene
  - Ready to go
- How often is calibration required?
  - Depends on application – recommended daily

18 - 10

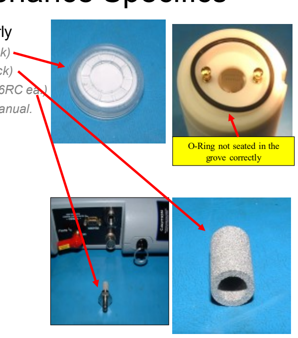
Using Tedlar Bags

- Using Tedlar Bags is the recommended method for calibration.
- Do not overfill to the point of bursting the bag.
- Do not use "Sharpies", "Marks-Alot" or similar markers. Pen or pencil only.
- <u>Always</u> open the bag before placing it on the water trap filter.
- Never run the bag empty.
- Do not mix sample types in one bag.
- Do not mix concentrations in one bag.
- Unexpected low readings may indicate a leaking bag. **

18 - 11

Other Maintenance Specifics

- Change Filters & O-Rings regularly
  - *Water Trap Filter (CR015DK : 10 Pack)*
  - *Particulate Cup Filter (620090 : 5 Pack)*
  - *Probe & Sample Port O-Rings (D0116RC ea.)*
  - *Other replacement parts are in the manual.*
- Change Sample line
  - *When discolored or*
  - *Contaminated*
- Clean detector capsules
  - *PID lens*
  - *FID gold pins*
- Detector cleaning instructions are in the manual
- Annual PM by Thermo is suggested. **



18 - 12

PID: Photo-Ionization Detector

- $4,000 to $6,000 per unit
- Lamp Energy (usually 10.6 eV so no ethane or propane) lamp energy must > ionization potential
- Benzene pre-treatment tube
- Data Logging and alarms
- Non-destructive (can collect air sample
- Photvac, RAE Systems & Ion Science
- Location records (GPS or aerial imagery)
- Identify locations for air sample collection

18 - 13

Photoionization detector Operation

- A PID is an ion detector which uses high-energy photons, typically in the ultraviolet (UV) range, to break molecules into positively charged ions.
- As compounds elute from the GC's column they are bombarded by high-energy photons and are ionized when molecules absorb high energy UV light.

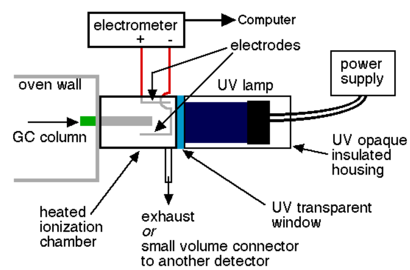
18 - 14

Photoionization detector Operation

- UV light excites the molecules, resulting in temporary loss of electrons in the molecules and the formation of positively charged ions.
- The gas becomes electrically charged and the ions produce an electrical current, which is the signal output of the detector.
- The greater the concentration of the component, the more ions are produced, and the greater the current

18 - 15

PID Operation



18 - 16

Other Methane Monitoring Instruments

- ✓Infrared detector (GEM 2000)
- ✓Catalytic oxidation detector (%LEL)
- ✓Thermal conductivity meter (% Gas)

18 - 17

Combustible Gas Indicator

Advantages

- Small and portable
- Internal battery
- Thermal mode for high or low O_2
- Easy to use
- "Safe"

Disadvantages

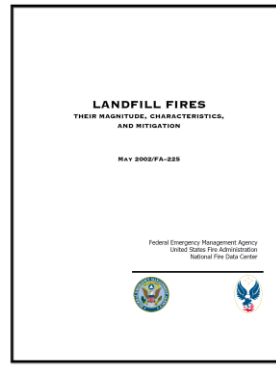
- Temperature dependent
- Calibration gas impacts results
- Catalytic mode problem with O_2
- Leaded gas, halogens, sulfur, silicon can harm filament
- CO_2 fouls O_2 cell

18 - 18

Landfill Fires and Smoldering Events

18 - 1

FEMA Landfill Fires Publication


LANDFILL FIRES
THEIR MAGNITUDE, CHARACTERISTICS, AND MITIGATION

MAY 2002/FA-225

Federal Emergency Management Agency
United States Fire Administration
National Fire Data Center

18 - 2

Landfill Fire Statistics from 2001

Each year, an average of 8,300 landfill fires causes up to $8 million in property loss.

Few casualties result from these fires.

Landfill fires are most prevalent in the spring and summer months, when there is a greater chance of spontaneous combustion.

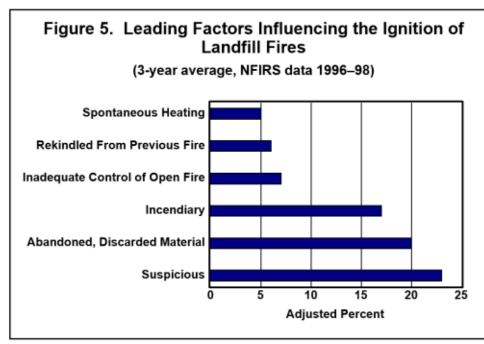
Landfill fires include not only refuse, but vehicles, structures, and surrounding brush and grass.

Fires at discarded tire sites produce large amounts of oil and smoke and are difficult to contain and extinguish.

Matches, open fire, and hot embers/ashes are the leading forms of heat ignition.

The cause of more than half of landfill fires is not reported; 40% are attributed to arson

18 - 3



18 - 4

Landfill Fire Examples

- On January 26, 1998, an employee at Richard DeCoite's construction and demolition (C&D) landfill in Ma'alaea, Maui, noticed an odd odor, which led to the discovery of a fire 15 to 20 feet underground. Attempts were made to smother it with injections of more than 1,000 pounds of liquid carbon dioxide. The fire was eventually deemed to be extinguished in a matter of weeks, although it continued to smolder for 4 months.
- An underground landfill fire that was discovered in December of 1996 in Danbury, New Jersey, caused an unpleasant odor (which smelled like rotton eggs due to the high concentration of hydrogen sulfide in landfills). The odor spread into two surrounding neighborhoods. The fire lasted for weeks and the town was forced to install a gas recovery system, whose cost exceeded $1 million

18 - 5

Bridgeton Sanitary Landfill Incident, Bridgeton, Missouri 2015

https://www.stltoday.com/business/local/epa-reaches-cleanup-decision-for-radioactive-west-lake-landfill-superfund/article_70796e6f-d975-5122-8670-16a67154b442.html

18 - 6

Mumbai Landfill Fire as Seen From Space

https://earthobservatory.nasa.gov/images/87429/fire-burns-in-mumbai-landfill 18 - 7

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Tire Fires
Landfill Fires Guidance Document
Best Management Practices for Pile Fires
Solid Waste Facilities Home

Home » Facilities » Fires » Landfill Fires Guide

Landfill Fires Guidance Document

Landfill fires, both surface and subsurface, are more common than one might expect. Although no one agency in the United States tracks the number of landfill fires a local search of web engines will indicate landfill fires have occurred from California to Minnesota and throughout the northern hemisphere. In California alone more than 25 subsurface landfill fires have been reported during the past 15 years. Most of the incidents are small fires or rapid oxidation events and are usually handled by the operating facility and the local or state regulatory agency. Seldom do the subsurface events become large-scale environmental responses.

Types of Landfill Fires

The most common types of fires occur at the surface, where fuel and oxygen are abundant. These fires can burn between the surface and one foot below ground. The other type smolders below ground and can extend down to 40 feet.

Surface Landfill Fires

A surface fire can start if the facility accepts hot objects (for example, barbeque coals or other ashes) or overdraws the landfill gas collection system. Also arson, spontaneous combustion, or a discarded cigarette can start fires. To keep fires small and manageable, immediate action is necessary. Actions may include using heavy equipment to remove the burning material to a safe area, the application of soil to suffocate the fire, or the use of suppression agent and firefighting activities. If no action is taken, significant amounts of rancid and toxic smoke will be generated from burning surface trash. Toxicity of this smoke depends on the composition of the waste stream.

https://www.calrecycle.ca.gov/swfacilities/fires/lffiresguide 18 - 8

Bridgeton Landfill
13570 St. Charles Rock Road
Bridgeton, MO 63044

Data Evaluation of the
Subsurface Smoldering Event
at the Bridgeton Landfill

For The

Solid Waste Management Program
Division of Environmental Quality
Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102

June 17, 2013

Prepared by
Todd Thalhamer, P.E.
Hammer Consulting Service
Cameron Park, CA 95682

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Data Evaluation Report, June 2013

Table 5. Proposed Sentry Criteria for the Construction of the Isolation Break at the Bridgeton Sanitary Landfill, Missouri.

Proposed Sentry Criteria [1, 2] — **Bridgeton Sanitary Landfill, North Quarry Isolation Break**

Indicator	Volume or/and Temperature	Isolation Break Required	Parameters
Carbon Monoxide (CO)			
CO levels in any gas extraction well or sentry monitoring well in the North Quarry.	>1,500 ppm	YES	CO result shall be repeatable and re-measured within 8 hours of receipt of the data. CO measurements shall be based on laboratory analysis and not field equipment. DNR and the fire authority shall be notified within 48 hours. Should any result exceed 1,500 ppm CO, the isolation break shall be constructed.
CO levels in two or more gas extraction wells and/or sentry monitoring well in the North Quarry.	>1,000 ppm	YES	Re-measure the initial CO result over 1,000 ppm within five days of receipt of the data. CO results greater than 1,000 ppm, but less than 1,500 ppm shall be re-measured 4 times for 4 weeks. DNR and the fire authority shall be notified within 5 days. Should all the retest exceed 1,000 ppm CO, the isolation break shall be constructed.
CO levels in any gas extraction well or sentry monitoring well in the North Quarry.	<1,000 ppm	No	No additional actions required. Continue monitoring per the First Agreed Order (Case No. 13SL-CC01088).
Temperature (°F)			
Any reportable temperature in a ***TMP*** at the sentry line[3] or in the North Quarry.	>200°F	YES	Temperature result shall be repeatable within 8 hours. DNR and the fire authority shall be notified within 48 hours. Should any temperature exceed 200°F in a TMP, the isolation break shall be constructed.
Any reportable temperature in a ***gas well*** located within the North Quarry.	>180°F	YES	Temperature result shall be repeatable within 8 hours. DNR and the fire authority shall be notified within 48 hours. Should any temperature exceed 180°F in a gas well, the isolation break shall be constructed.
Combination of CO + °F			
Any reportable temperature in a ***TMP*** or ***gas well*** at or past the sentry line exceeding 195°F and any gas well in the North Quarry exceeding 1,500 ppm CO.	>195°F + >1,500 ppm	YES	Temperature result shall be repeatable within 8 hours. DNR and the fire authority shall be notified within 48 hours. Should any temperature exceed 195°F in a gas well in the North Quarry and CO is detected above 1,500 ppm at the sentry line or North Quarry, the isolation break shall be constructed.
Any reportable temperature in a ***TMP*** less than 195°F or ***gas well*** located within the North Quarry or sentry line with CO less than 1,000 ppm.	<195°F + <1,500 ppm	No	Temperature(s) shall be collected weekly. Continue monitoring per the First Agreed Order (Case No. 13SL-CC01088).

[1] These criteria are in addition to the First Agreed Order of Preliminary Injunction (Case No. 13SL-CC01088) between the State of Missouri and the Bridgeton Sanitary Landfill, LLC.
[2] The temperature and CO levels for this matrix are for the establishment of a trigger value and not for the confirmation of a smoldering event.
[3] The sentry line for this matrix is currently defined as TMP-1 through TMP-4 on the Well Layout Plan by SCS Engineers, date 1/10/2013.

18 - 10

Bridgeton Landfill 2013

Photo 2. Damage Gas Collection Well (Source: DNR Staff, 2012).

Photo 3. Heat Deterioration of FML, Measured Temp. 128°F, April 2013 (Source: DNR Staff, 2013)

Photo 4. Excessive Landfill Gas and Inflated FML, May 2013 (Source: DNR Staff, 2013).

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