Solid Waste Management: US EPA Lined-Landfill Approach Not Reliable for Protecting Public Health and Environmental Quality[1]

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Abstract

Historically, municipal solid waste disposal has been conducted by disposal on low-value lands where the wastes were burned in open pits. Beginning in the 1950s, in some more developed areas, the landfilling of municipal and industrial wastes occurred in "sanitary" landfills. Sanitary landfills differed from the open-pit burning and disposal since burning was no longer allowed, and each day's waste was covered with a thin layer of soil. This soil layer was designed to reduce, but not necessarily eliminate releases of odor and prevent vermin from entering into the waste. The sanitary landfill does not address the pollution of groundwaters by landfill leachate (garbage juice). Beginning in the 1980s, in some developed countries, the disposal in municipal landfills of large amounts of highly hazardous industrial wastes was prohibited.

In the USA, these so-called "hazardous" wastes had to be detoxified and disposed of in lined hazardous waste landfills. The municipal and industrial so-called "non-hazardous" wastes were to be disposed of in municipal landfills. In the early 1990s, the US Environmental Protection Agency (US EPA) adopted Subtitle D landfilling regulations for disposal of municipal solid waste. This approach is being used today, where there is an attempt, through the use of inexpensive bottom liners and landfill covers, to initially isolate the waste from moisture in a "dry tomb" approach. A minimum Subtitle D landfill is a plastic sheeting and compacted clay lined landfill that, at best, only postpones when groundwater pollution occurs.

It has been known from the beginning that the "dry tomb" Subtitle D landfill disposal system for municipal solid waste (MSW) is a fundamentally flawed approach for providing groundwater quality and environmental protection from waste-associated constituents for as long as the wastes will be a threat to public health, groundwater quality and the environment. Many of the municipal solid waste components in today's Subtitle D "dry tomb" landfills will be a threat to public health, groundwater resources and the environment, effectively, forever. With proper construction, the plastic sheeting and compacted clay liners can prevent groundwater pollution for a short period of time compared to the time that the wastes will be a threat to cause pollution.

While the US EPA, as part of adopting Subtitle D regulations, assumed without adequate evaluation that the eventual failure of the liner system to prevent leachate from passing through it, leading to groundwater pollution, would be detected by the groundwater monitoring system used, it has been known since the late 1980s that the groundwater monitoring systems used at Subtitle D landfills, which are based on vertical monitoring wells spaced 30 or more meters apart, are highly unreliable in detecting leachate pollution of groundwater before widespread pollution occurs.

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Basically, today's minimum Subtitle D landfills in the USA and other countries that have adopted this approach are cosmetic with respect to protecting public health, groundwater quality and the environment from the hazardous and otherwise deleterious constituents in municipal solid waste for as long as the landfilled wastes will be a threat. There is growing recognition in the USA and in some other areas that the "dry tomb" landfill with a single composite liner is not a reliable solid waste management approach. Fundamentally, it passes the true cost of solid waste disposal on to future generations, in terms of having to clean up polluted groundwaters and having to experience the loss of water resources. The US EPA Subtitle D landfills are not an acceptable approach and should not be copied by countries for developing MSW landfills.

Municipal and industrial solid wastes should be recycled to the maximum extent practicable in order to conserve natural resources and to reduce the number of needed landfills for MSW management that have the potential to eventually pollute groundwaters. The non-recyclable reusable waste residues should be disposed in double composite lined landfills where the a leak detectable layer between the two composite liners is used as a leak detectable system for upper composite liner.

Keywords: Landfills, Municipal Solid Waste Disposal, Sanitary Landfills, Groundwater Pollution, Waste Recycling

Introduction

The appropriate management of municipal and industrial solid waste continues to be a major problem throughout the world. Traditionally, following the Dark Ages, solid waste management was practiced through transporting the solid wastes to nearby low-value lands for disposal. Frequently then, and, in some parts of the world, today, the combustible parts of the solid wastes were set afire at the disposal site. This practice, while now terminated in many developed countries, is still in use in some developing countries.

Development of the Sanitary Landfill

Beginning in the 1950s, in the USA and a number of other countries, the open-landfill, with or without burning, method of solid waste disposal was changed to what became known as the "sanitary" landfill, where burning was stopped and a few inches of soil was placed over the waste at the close of each day. When the landfill became full, some additional soil was placed over the landfill to grade the landfill surface. Sometimes these closed landfills were then used for parks, industrial/commercial development and other purposes. While the sanitary landfill, if properly operated in accord with recommended procedures, addressed to some degree some of the most significant problems associated with landfills, such as severe odors, they did not and do not address some of the most significant problems associated with landfilling of municipal solid wastes and many industrial solid wastes.

Justified NIMBY

Throughout history, those owning property, living, or working near municipal and industrial landfills have had a justified "NIMBY" (not in my back yard) approach toward the siting of a new landfill, expanding existing landfills and the continued operation of landfills. This justified NIMBY

stems from the fact that the landfill developers, whether public agencies or private entities, do not address at all, or do not adequately address, the many adverse impacts of solid waste landfills on those within the sphere of influence of the landfill. This sphere of influence is normally intense within a mile (several kilometers) of the landfill, and can readily extend several miles from the landfill. Lee and Jones-Lee (1994a) discussed the variety of factors that influence the ability of an operating or closed sanitary landfill to be adverse to those within the sphere of influence of the landfill. These include:

- public health, economic and aesthetic aspects of groundwater and surface water quality
- methane and VOC migration - public health hazards, explosions and toxicity to plants
- illegal roadside dumping and litter near landfill
- truck traffic
- noise
- dust and wind-blown litter
- odors
- vectors - insects, rodents, birds
- condemnation of adjacent property for future land uses
- decrease in property values
- impaired view.

Lee and Jones-Lee (2008) have provided a overview discussion of the potential impact of municipal solid waste landfill.

Resource Conservation and Recovery Act (RCRA),

Beginning in the 1970s in the USA and in several other developed countries, associated with the finding that municipal sanitary landfills were causing severe groundwater pollution in the vicinity of the landfill, regulatory agencies such as the US EPA have been developing approaches to minimize/control groundwater pollution by the landfilled wastes. Under the US Congress' Resource Conservation and Recovery Act (RCRA), industry and commerce were prohibited from disposal of large amounts of industrial solvents in municipal landfills. Prior to that time, 55-gallon drums of solvents and other chemicals of industrial origin were dumped in municipal landfills.

RCRA established the management of what became classified as "hazardous" wastes in hazardous waste landfills, which under US regulations are called "Subtitle C" landfills. These landfills were required to be lined, initially with a clay liner, then a plastic-sheeting liner, then, when both of these were found to readily fail to prevent groundwater pollution, a composite liner of clay and plastic sheeting, then, when the single composite liner was found to fail, a double composite liner. The typical Subtitle D landfill is shown in Figure 1 Today's RCRA (Subtitle C) landfills consist of a double composite liner of clay and plastic sheeting, with a leak-detection system between the two composite liners (see Figure 2). Further, Subtitle C landfilled wastes must be detoxified/immobilized to some extent before disposal.

Figure 1
Single Composite Liner Landfill Containment System

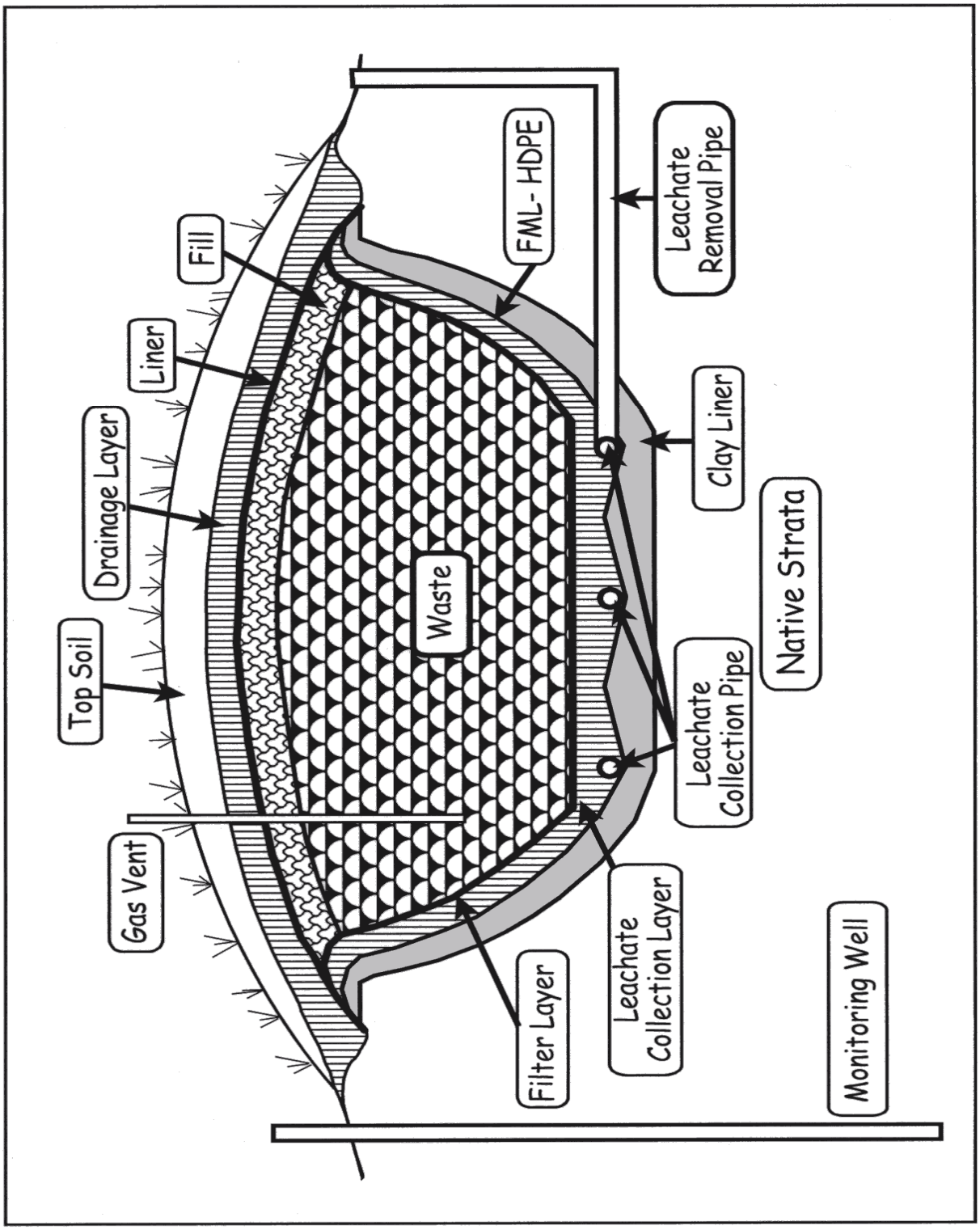
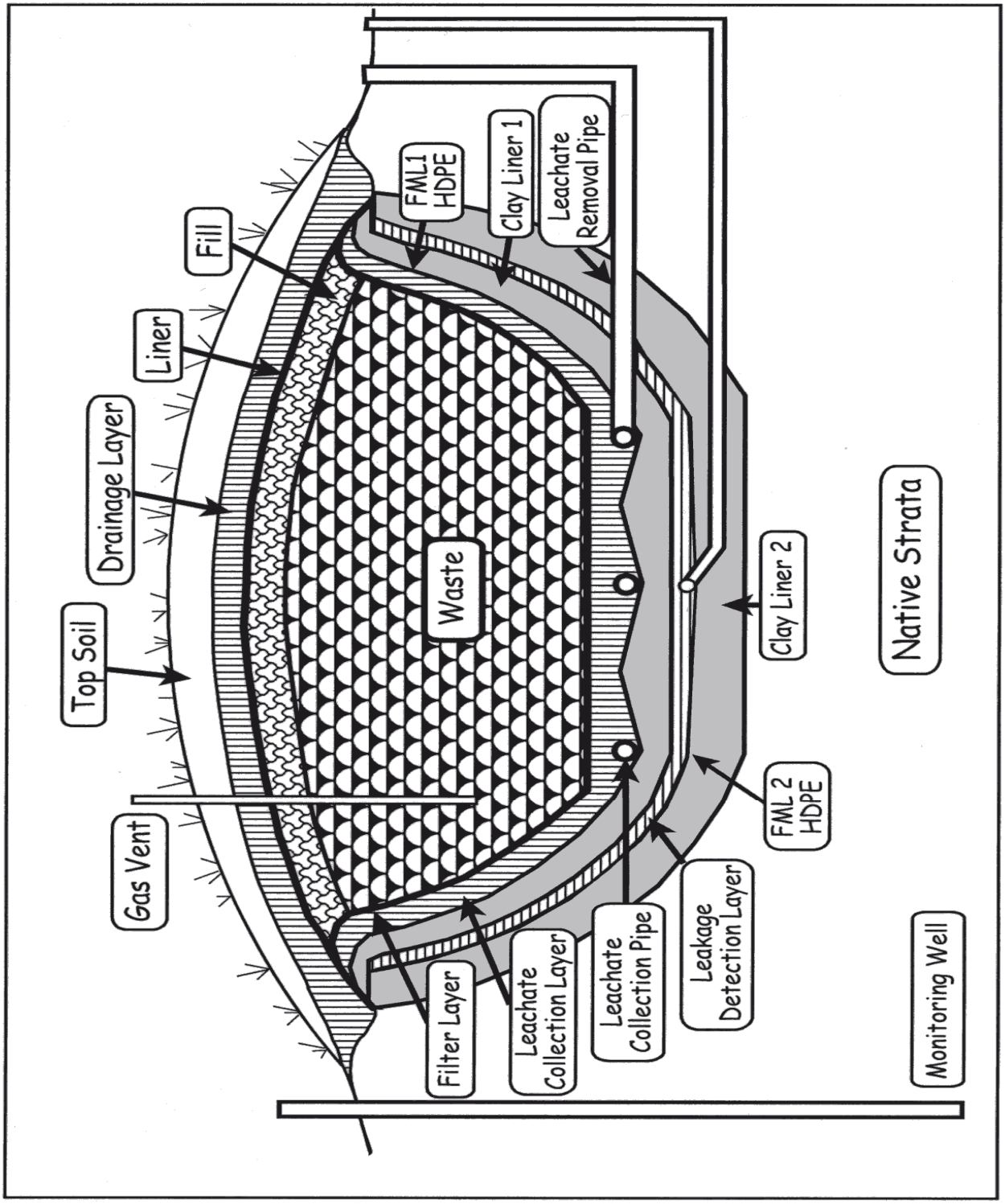


Figure 2
Double Composite Liner Landfill Containment System



Classification of Hazardous Waste

The US EPA, as part of implementing RCRA, developed a definition of hazardous waste, which was designed for political purposes to minimize the amount of hazardous substances disposed of in municipal "Subtitle D" landfills. Highly ignitable, explosive or corrosive wastes were prohibited from disposal in Subtitle C and D landfills. The characteristic of the wastes that made them hazardous had to be eliminated through treatment. The US EPA developed the Extraction Procedure Toxicity Test to evaluate waste constituents with respect to their potential to cause groundwater pollution. The EP Tox test was soon recognized as a seriously flawed test in preventing groundwater pollution by hazardous chemicals in municipal landfills. The US Congress ordered the US EPA, as part of revising RCRA, to develop a more reliable test. The US EPA modified the EP Tox test to develop the Toxicity Leaching Characteristic Procedure (TCLP) test. While this test addresses some of the problems of the EP Tox test, it still is seriously flawed as a testing procedure that would be effective in keeping hazardous chemicals out of municipal landfills.

While landfill owner/operators and some regulatory agencies will claim, as part of developing a new Subtitle D landfill, that the landfilled wastes will not be hazardous wastes, this claim is superficial with respect to the landfilled wastes not containing hazardous chemicals, which are a threat to public health and the environment through release from the landfill in either landfill gas or leachate that penetrates through the liner system into the underlying groundwaters. The net result is that the chemical pollution of groundwaters (such as by chlorinated and other solvents), which originally caused the development of RCRA and distinguishing between municipal solid waste (Subtitle D) and hazardous waste (Subtitle C) landfills, has been reduced, but it has not been eliminated. Today's municipal solid waste leachate still contains a variety of hazardous and deleterious chemicals that can be significantly adverse to groundwater quality, with respect to its use for domestic water supply and some other purposes.

While the focus of most regulatory attention with respect to groundwater pollution by landfill leachate is the management of so-called hazardous wastes and, to some degree, hazardous chemicals, it should be understood that, even if there were no hazardous chemicals placed in a municipal or industrial landfill, the leachate would still be a significant threat to destroy groundwater polluted by this leachate as a domestic water supply source. The US EPA, as part of promulgating Subtitle D regulations in 1988, recognized that the conventional pollutants in leachate, including constituents that cause tastes and odors, would cause a water supply well that receives leachate-polluted groundwater to have to be abandoned, since the water would be unusable for domestic purposes. Tastes and odors and other constituents in the water would cause a water utility or individual to conclude that they must develop a new well at some distance from the old well in order to develop a suitable groundwater-based water supply.

Jones-Lee and Lee (1993) have provided a general discussion of the potential for municipal solid waste leachate to pollute groundwaters, rendering them unusable for domestic water supply purposes. They point out that municipal solid waste leachate from Subtitle D landfills conforming to current RCRA requirements still contains hazardous and non-hazardous constituents that are a significant threat to pollute groundwaters, rendering them unusable for domestic water supply purposes. It is known that groundwaters polluted by landfill leachate can never be cleaned up so that

they would represent a safe, dependable water supply. Even if the groundwaters that had been polluted at one time by municipal landfill leachate, or the aquifer that had groundwaters with leachate pollution in it, met all drinking water standards, the waters could still readily contain hazardous and deleterious chemicals that are not measured in groundwater pollution studies (Lee and Jones-Lee, 1994b). There are over 75,000 chemicals in commerce today. There are many thousands of chemicals that could be present in municipal and industrial solid waste landfills, which can be present in leachate derived from these landfills and polluted groundwaters that have received leachate. Only about 200 out of the 75,000+ chemicals that are in commerce are investigated in groundwater pollution investigations near landfills. As a result, any groundwater or aquifer system that has received leachate from municipal or industrial landfills will always be suspect with respect to whether it is safe to consume this water, even if drinking water MCLs are met.

An area of particular concern is so-called non-hazardous waste landfills for industrial wastes. These landfills can readily contain leachate that is both hazardous and detrimental to groundwater quality and to surface waters that are impacted by leachate-polluted groundwater discharges to surface waters. While the US EPA was supposed to, in accord with the last revision of RCRA, develop Subtitle D regulations for non-municipal solid waste, this has not been done, with the result that the regulation of industrial solid waste that is classified as "non-hazardous," is left up to the states, many of which have done little to properly evaluate how best to manage these wastes. As a result, industrial "non-hazardous" wastes are often managed in the equivalent of a Subtitle D landfill with a single composite liner.

Subtitle D Landfills

In 1988 the US EPA promulgated Subtitle D regulations, where they indicated that all municipal solid waste disposal in landfills must take place in such a way as to protect groundwaters from pollution (impairment of use) at the point of compliance for groundwater monitoring. The Agency indicated that the minimum Subtitle D landfill must be lined with a single composite liner, consisting of two feet of clay compacted to a 10^{-7} cm/sec permeability overlain by a 60 mil (60 thousandths of an inch) high-density polyethelene (plastic sheeting) liner. The Agency did not specify that this minimum design would be protective at all locations where landfills could be located. The US EPA acknowledged in 1988 that, eventually, the Subtitle D single composite liner would fail to prevent groundwater pollution by landfill leachate.

The US EPA (August 30, 1988a) Solid Waste Disposal Criteria state,

> *"First, even the best liner and leachate collection system will ultimately fail due to natural deterioration, and recent improvements in MSWLF (municipal solid waste landfill) containment technologies suggest that releases may be delayed by many decades at some landfills."*

The US EPA (July 1988b) Criteria for Municipal Solid Waste Landfills state,

> *"Once the unit is closed, the bottom layer of the landfill will deteriorate over time and, consequently, will not prevent leachate transport out of the unit."*

The US EPA at the time of initial promulgation of the Subtitle D regulations faced a threat of a court order arising from litigation initiated by environmental groups for failure to comply with RCRA requirements for promulgating regulations for the landfilling of municipal solid waste as required by the reauthorized RCRA. This situation led to the Agency adopting Subtitle D regulations that were known or should have been known at that time would only postpone when groundwater pollution occurs.

The US EPA (Bonaparte, *et al*., 2002) has released a report that claims that the single composite lined landfill liner can be expected to have a service life of "1,000 years." A critical review of the technical base for this estimate shows that it is based on an Arrhenius equation extrapolation of a few studies on liner stability that were conducted for a short period of time at elevated temperatures compared to landfill temperatures. The approach for extrapolation is highly speculative and likely to be unreliable. This report continues to support the US EPA (1988a,b) conclusion about the eventual failure of the landfill liner system leading to groundwater pollution. While the length of time that the landfill liner will prevent groundwater pollution is unknown, there is no doubt that the landfill liner system will eventually fail and groundwater pollution will occur when the landfill is sited at locations where there is high-quality groundwater underlying the landfill.

In the US EPA (Bonaparte, *et al*., 2002) report, Koerner makes a significant error in claiming that the municipal solid wastes in a Subtitle D landfill will only be a threat for about 200 years. There is no technical validity for this estimate. It is obvious that in a "dry tomb" landfill, a number of the normal components of MSW will be a threat forever -- not just 200 years. The metals, salts, and many organic compounds that are typically present in MSW that produce hazardous and deleterious leachate will be a threat forever. In this report the Agency is attempting to support the continued use of single composite lined landfills for MSW management by claiming the wastes will only be a threat for 200 years, and the liner will work perfectly for 1000 years.

An important issue that the US EPA (Bonaparte, *et al.*, 2002) fails to discuss is that the plastic sheeting HDPE liner will allow dilute solutions of organic solvents such as those that can be purchased in hardware stores to pass through an intact (no holes) liner. This issue has been investigated by Park, *et al.* (1996a,b), who found that dilute solutions of several low molecular weight solvents passed through HDPE liner material in a few days. This is an important issue since many of these solvents are carcinogens. The US EPA needs to address this issue as part of recommending composite liner systems for municipal solid wastes.

Lee and Jones-Lee (2010) in their "Flawed Technology" review have provided detailed discussion of the factors that cause minimum design Subtitle D landfill liners to eventually fail to prevent groundwater pollution by landfill leachate.

Unreliability of Groundwater Monitoring

The US EPA (Bonaparte, *et al*., 2002) report does not discuss that when the landfill liner eventually fails to prevent groundwater pollution, the polluted groundwater cannot be reliably monitored to detect the pollution before offsite pollution occurs. As discussed by Lee and Jones-Lee (1998a,b,

2010), the basic problem is that the regulatory agencies at the federal and state levels allow landfill owner/operators to monitor leachate pollution of groundwaters with monitoring wells spaced 30 to as much as a hundred or more meters apart along the point of compliance. Each of these monitoring wells has a zone of capture of groundwater of about one foot (0.3 meter) from the well -- i.e., three well bore-hole volumes -- for a homogeneous sand aquifer system. For fractured rock or sandy lenses, the capture zone can be significantly different, making monitoring of groundwaters in those regions highly unreliable. As discussed by Lee and Jones-Lee (1998a,b), Cherry (1990) pointed out that the initial leakage from a plastic-sheeting-lined landfill will be finger plumes of leachate, which will be no more than a few meters wide at the point of compliance. Therefore, if monitoring wells are spaced 30 meters apart at the point of compliance, and the monitoring wells can best "see" polluted groundwater to the extent of 0.3 meter on each side, then there are about 29 meters between monitoring wells through which finger plumes of leachate of considerable size can pass and not be detected by the monitoring well system. The US EPA staff, in discussing this issue, indicate that that is not a fault of RCRA Subtitle D, but of those who allow such a grossly inefficient, largely cosmetic groundwater monitoring system to be used to implement Subtitle D requirements for groundwater monitoring. As discussed by Lee and Jones- (2010) fundamentally, Subtitle D regulations are seriously flawed with respect to protecting offsite groundwaters from pollution by landfill leachate for as long as the wastes in the landfill will be a threat.

Problems of the unreliability of groundwater monitoring in Subtitle D landfills to detect groundwater pollution before widespread offsite groundwater pollution has occurred are well-recognized. States like Michigan, and a number of others, require double composite lined municipal solid waste landfills (see Figure 2) These liners are similar to those required for hazardous waste landfills. They also require that a leak-detection system be used between the two composite liners to determine when the upper Subtitle D composite liner has failed. This approach, where the lower composite liner is a pan lysimeter for the upper composite liner, is a far more reliable monitoring approach for detecting liner leakage than the single composite liner with wells spaced along the point of compliance. The single composite liner monitoring system is best characterized as "cosmetic," which enables landfills to be installed at far less than their true cost, where future generations will bear the burden of the cost of municipal solid waste management for the current generation, through threats to their health, groundwater resources and other interests.

The primary problem with the double composite lined system, such as required by Rule 641 in the state of Michigan, is that neither Michigan nor other states like New York and New Jersey require that adequate funding be set aside in a dedicated trust to be able to take action to prevent groundwater pollution when the upper composite liner has failed. This situation points to another serious flaw with RCRA requirements for both Subtitle D and C landfills, where landfill owner/operators, whether public or private, are not required to ensure that there is adequate funding to address the plausible worst-case scenario failure of the liner system and the groundwater monitoring system for as long as the wastes in the landfill are a threat.

Inadequacy of Post-Closure Care Funding

Current post-closure funding for Subtitle D landfills is only required to a limited extent for 30 years beyond the closure of the landfill. There is no assured funding beyond that date. It will almost

certainly be difficult to get private landfill companies, as well as public agencies, to provide funds from year 31 on, when it is found that groundwater pollution is beginning to occur. Today's minimum single composite liner for a Subtitle D landfill, if properly installed and not punctured at the time that the wastes are placed in the landfill, should be able to prevent groundwater pollution by landfill leachate through the mandated 30-year post-closure care period. Lee and Jones-Lee (2011) have provided additional information on the need for postclosure monitoring, maintenance and groundwater remediation for as long the wastes in the landfill when contacted by water can generate leachate. In a dry tomb type landfill this period can be effectively forever.

Basically, this situation is leading to the development of what will be equivalent Subtitle D Superfund (hazardous chemical) sites, where groundwaters near Subtitle D landfills will, at some time in the future, have to be investigated and remediated, much like is being done today for Superfund sites. The failure of Congress, through authorization of RCRA, and the US EPA to establish a funding source for plausible worst-case landfill liner failure and groundwater monitoring system failure to prevent offsite groundwater pollution by landfill leachate for as long as the wastes in the landfill will be a threat is one of the most significant deficiencies in the current Subtitle D regulations. This situation virtually assures that there will be future "Superfund" sites at today's municipal Subtitle D landfills.

Inadequate Landfill Cover Maintenance

Another significant deficiency in Subtitle D landfilling is the failure to require effective landfill cap (cover) maintenance for as long as the waste in the landfill will be a threat to generate leachate. The approach that is used in permitting landfills, where the landfill owner/operator is able to claim that examination of the surface of the landfill cap can detect when the low-permeability layer of the cap has deteriorated to the point so that there is substantial moisture entering the landfill that will generate leachate that will eventually pollute groundwater, is another of the superficial approaches that accompany implementation of the Subtitle D landfilling regulations. The facts are that the plastic-sheeting layer in a Subtitle D cap can and will deteriorate, allowing moisture to pass through the soil cover to penetrate into the wastes, rather than be transported by the plastic sheeting off of the cover.

While the US EPA and other regulatory agencies allow landfill proponents to claim that the HELP model can be used to predict leachate generation within the landfill, such claims are another of the superficial approaches used in permitting landfills. It is obvious that the HELP model cannot reliably predict leachate generation over the time that the wastes in the landfill will be a threat. The rate of deterioration of the plastic-sheeting layer in the cover and the associated moisture entering the landfill cannot be reliably predicted. All of the so-called HELP model calculations apply only to initial design, and provide no relevant information to long-term situations which can lead to leachate generation within the landfill. Lee and Jones-Lee (1998a) have discussed the fact that it is possible with today's technology to install leak-detectable covers on landfills, which would indicate when the landfill cover has developed a leak. This technology allows the determination of the area of the cover where the leak occurs, thereby enabling repairs to take place. While this technology is readily implementable today, neither the US EPA nor the state regulatory agencies require its use, since it would require that public and private landfill owner/operators operate and maintain the leak-

detectable cover forever. For largely political reasons of not wanting to increase the cost of municipal solid waste management, regulatory agencies are allowing the practice of cheaper-than-real-cost garbage disposal to those who generate the waste.

Groundwater Pollution by Subtitle D Landfills

Frequently, landfill advocates will state that there is no evidence that minimum Subtitle D landfills have polluted groundwaters as support for permitting a new or expanded Subtitle D landfill. This statement is inappropriate with respect to asserting that previously permitted and new minimum Subtitle D landfills will not inevitably pollute groundwaters that underlie the landfill. There are several reasons why minimum Subtitle D landfills have not been found to pollute groundwaters, one of the most important of which is that minimum Subtitle D landfills have, in general, only been constructed over the past 20 years. Unless there was extremely sloppy construction of the single composite liner, leachate would not be expected to have passed through the underlying clay liner for about 25 years. In addition, there would be a period of several years, depending on the hydrogeology of the area, before the polluted groundwaters associated with liner leakage would reach the point of compliance for groundwater monitoring.

Further, and most important, is the fact that the monitoring systems used to detect leakage of a minimum Subtitle D landfill liner system are inherently unreliable. As discussed above, the typical vertical monitoring well groundwater pollution detection approach has a low probability of detecting groundwater pollution by landfill leachate when it first reaches the point of compliance for groundwater monitoring. Overall, groundwater pollution by minimum Subtitle D landfills would not be expected to be detected at this time. However, this does not mean that the previously permitted and new Subtitle D landfills will not pollute the groundwaters underlying the landfill at essentially all locations where such landfills are sited.

There are several reports in the literature of upper composite liner failure for municipal solid waste landfills where a double composite liner was required by the regulatory agency. While proponents of the single composite lined municipal solid waste landfill assert that these failures were likely due to improper construction or punctures of the liner with initial waste placement, the facts are that, even with high-quality construction and careful waste placement, failures of single composite liners have been found to occur. The reason that these failures have been found is that leachate has appeared in the leak detection system between the two composite liners. Without the lower composite liner and its associated leak detection system, these failures would not likely have been observed for many years.

Landfill Gas

One of the major threats of landfills is the production of methane and other gases that are a threat to the health, welfare and interests of those in the vicinity of the landfill. Landfill gas from municipal solid waste landfills contains a variety of constituents that are a threat to public health. Methane itself, in the right proportion with oxygen, is an explosive hazard. Further, it is well-known that today's municipal solid waste landfills contain a variety of volatile organic chemicals which are known carcinogens, such as vinyl chloride and other chlorinated and non-chlorinated gaseous products, which are a threat to human health and to animal health. This threat can extend for

considerable distances from the landfill. There is concern about the reoccurring observation that people living near municipal solid waste landfills tend to have a higher incidence of disease than those who do not live within the sphere of influence of a landfill. Elliott, *et al*. (2001) have reported that children of people living near landfills in England tend to have a higher rate of birth defects than the general population.

The typical approaches that are used in an attempt to manage landfill gas, which is either passive (focusing on natural ventilation) or active (in which a reduced pressure is used on a landfill gas collection system), are often superficial and collect only part of the landfill gas emissions. Gas emission pathways through the cover allow gases to escape and not be collected by the collection system. Further, even a well-designed system can encounter significant operational problems, due to the failure to maintain the gas collection system for as long as the landfill wastes can produce gas. The period of time that landfill gas production can take place is another of the superficially addressed issues that occur in permitting of landfills.

As discussed by Lee and Jones-Lee (1999), the production of landfill gas is dependent on moisture in the waste. Once the landfill is closed and a high-quality plastic-sheeting layer is installed over the landfill as part of the cover, there can be a period of time when landfill gas production and, for that matter, leachate production, can become very low. The typical gas production versus time curves presented by landfill applicants and their consultants have little or no validity in describing the period of time and rates of landfill gas production on closed "dry tomb" landfills. This is a result of the fact that it is impossible to predict the rate of moisture entry into the landfill through cracks, holes, points of deterioration, etc., that occur in the plastic-sheeting layer of the cover. It is these areas that control the amount of moisture that enters the landfill, which in turn leads to landfill gas generation after the cover has been placed on the landfill.

Another aspect of landfill gas production that is inadequately addressed is that, in the USA and in some other areas, large amounts of the municipal solid waste deposited in the landfill are placed in polyethelene garbage bags. These bags are typically crushed in the landfill through the compaction process. They are not, however, shredded, with the result that the garbage in the bags is "hidden" to a large extent from the moisture that enters the landfill through leaks in the cover. This then creates a situation where there will be landfill gas production due to the moisture that enters the landfill while the landfill is open, receiving wastes. When it is closed and the low-permeability cover is installed, the gas production will decrease, possibly going to zero for a period of time. In time, due to the failure of current regulatory approaches to require proper maintenance of the landfill cover low-permeability layer, moisture will start to enter the landfill again. It will lead to the fermentation of any of the readily exposed fermentable solid waste components.

Depending on the amount and distribution of moisture entering the landfill, the exposed readily fermentable components will produce gas over a period of several decades, and, again, landfill gas production will become slow, this time due to lack of fermentable waste components that can be exposed to the moisture that enters the landfill. Meanwhile, over many decades, the plastic bags that are used to contain the garbage, will slowly decay. As these bags decay, moisture that is continuing to enter the landfill through the now highly deteriorated cover will enable landfill gas production to

start again. This could be many decades in the future. By that time, the landfill gas collection system has deteriorated, there are no funds for maintenance, and there could readily be no funds for monitoring of landfill gas production.

One of the most significant landfill gas emissions is the odorous compounds. Landfill odors are notorious for causing people at considerable distances, of a mile (several kilometers) or more, to justifiably object to a landfill in their area. While landfill odors are typically considered a nuisance, as discussed by Lee and Jones-Lee (1994a, 1998a), landfill odors can represent significant health threats to individuals who are sensitive to the odorous compounds or just the presence of odors. Shusterman (1992) has found a direct link between highly odorous situations such as landfills and human health.

Addressing Justified NIMBY

Landfills should be designed, constructed, operated and maintained so that an adjacent property owner or user can be present at the property line and not know that the landfill is there based on odor. Failure to follow this approach leads to justified NIMBY, where the landfill owner/operator (and the public who disposes of waste at that landfill) has established an inadequate buffer between the waste disposal areas and the adjacent properties. Typically, at least a mile (several kilometers), and in some situations, several miles, of landfill-owned property should exist between waste deposition areas and an adjacent property. The size of this area depends on how well the landfill owner/operator controls the releases from the landfill. Typically, at least a mile of buffer lands is needed for landfill gas/odor dissipation during the active life and after the landfill is closed.

The US EPA, in developing Subtitle D, claimed that these regulations should eliminate justified NIMBY. However, the Agency staff who made that claim do not understand NIMBY, have never worked or lived next to a landfill, and certainly have no understanding of how municipal and industrial solid (non-hazardous waste) landfills can be adverse to those within the sphere of influence of the landfill. The US EPA, in developing Subtitle D regulations, allows a landfill owner to deposit wastes essentially up to the property line of adjacent properties. There is no mandatory minimum buffer. We dare say that if those who developed Subtitle D regulations lived immediately adjacent to a typical Subtitle D landfill, they would quickly see that the regulations they developed are flawed in many respects, one of the most important of which is the failure to provide adequate buffer land between waste deposition areas and adjacent properties.

As discussed herein and in the references provided, there are many deficiencies in Subtitle D landfilling of wastes, in properly managing solid wastes in a landfill that will be protective of the health, welfare and interests of those within the sphere of influence of the landfill who can be impacted by it. It is the author's experience that other countries' regulatory agencies are adopting the US EPA's Subtitle D regulatory approaches for managing municipal solid waste without evaluating the highly significant deficiencies in this landfilling approach in protecting public health and the environment from waste-derived constituents for as long as the waste in the landfill will be a threat. As discussed in Lee and Jones-Lee (2010), "dry tomb" Subtitle D landfills are obviously fundamentally flawed in providing long-term public health and environmental protection from the adverse impacts of municipal solid waste and industrial solid waste landfills.

Bioreactor - Leachate Recycle

There is growing recognition that the "dry tomb" landfilling approach, originally prescribed by environmental groups and adopted by the US Congress, is a fundamentally flawed approach for managing municipal solid waste. The USA and many other countries' societal constraints preclude protective design, operation, maintenance and post-closure care for as long as the wastes in the landfill will be a threat. In order to begin to address the issue of the long-term threat of municipal solid waste landfills, various individuals and governmental agencies are advocating the "bioreactor" landfilling approach, in which leachate generated within the landfill is added back to the landfill as a source of moisture. The additional moisture enhances fermentation of the decomposable components of the waste.

Lee (2000a,b) and Jones-Lee and Lee (2000) have reviewed the problems with the approach that is being advocated for leachate recycle in minimum Subtitle D landfills. This approach is not a reliable approach for treating landfilled municipal solid wastes. In fact, it may cause greater groundwater pollution. Jones-Lee and Lee (2000) recommend that leachate recycle be practiced in double composite lined landfills, where the wastes placed in the landfill are shredded to allow the leachate to interact with all waste components. After the landfill effectively stops producing gas, a clean-water wash (leaching) of the wastes should be practiced to remove any residual leachable, non-fermentable components that are a threat to cause groundwater pollution. Adoption of this approach would produce a true, protective bioreactor that could produce a stabilized municipal solid waste residue that has little potential to cause groundwater pollution.

Overall Assessment

Lee and Jones-Lee (2010) provide additional information on the deficiencies of minimum Subtitle D landfills and why other countries should not pattern their landfilling practices after Subtitle D. They need to critically evaluate, based on their needs, the importance of controlling the releases from the landfill that can be adverse to the public and the environment over the infinite period of time that the wastes in the landfill will be a threat.

While some countries such as Germany are restricting the amount of organic waste that can be placed in a landfill, thereby reducing the amount of fermentable wastes that can lead to landfill gas, it is important to understand that the landfills, even without biodegradable waste, are still a threat to cause groundwater pollution through the salts, metals and other constituents that are present in municipal and/or industrial solid wastes that are not fermentable.

Professional Ethics Issues

It is appropriate to inquire why there is not greater discussion of the significantly flawed approach of Subtitle D landfilling. It is the author's experience that these issues are well-understood by many of those in regulatory agencies and in the landfill consulting community; however, as discussed by Lee and Jones-Lee (1995), there is a significant professional ethics issue associated with the permitting of landfills, where those who develop landfills for public and private agencies do not discuss these problems, since it would mean that their firm would not gain further work from landfill developers.

Landfill permitting in the USA is conducted in an adversarial arena, where landfill applicants and their consultants only discuss the positive aspects of a proposed landfill, and do not discuss the problems associated with the landfill. This provides regulatory bodies responsible for permitting landfills with an unreliable information base upon which to make decisions on the permitting of a landfill. Lee and Jones-Lee (1995) recommend that the current adversarial landfill permitting approach be replaced by a publicly conducted interactive peer review process, where both the positive and negative aspects of a proposed landfill can be discussed. Adoption of this approach would greatly improve the reliability of the information provided to regulatory agencies as part of permitting of landfills.

Recommended Landfilling Approach

Lee and Jones-Lee (1998a, 2010) have recommended a landfilling approach that would provide a high degree of public health, groundwater resource, and environmental protection. The recommended approach involves properly siting the landfill with adequate buffer lands. Of particular concern are geologically unsuitable sites such as those with fractured rock or cavernous limestone underlying the landfill. Further, siting of a landfill within several miles (5 or so km) of an existing or potential groundwater water supply source should be avoided. The landfill should be constructed with a double composite liner which contains a leak detection layer between the two composite liners. When leachate is found in this leak detection system, either the waste in the landfill must be exhumed or a leak-detectable cover must be installed, operated, and maintained in perpetuity.

Only shredded non-recyclable waste should be placed in the landfill. An active landfill gas collection system should be operated and maintained for as long as the waste in the landfill has the potential to generate landfill gas. All collected landfill gas should be recovered and utilized as an energy source. All landfill gas pollutants should be managed in such a way as to prevent a significant threat to public health and the environment. The disposal fees associated with landfilling should be of sufficient magnitude to develop a dedicated trust fund that will ensure that all plausible worst-case liner failures and groundwater monitoring system failures can be adequately addressed before offsite pollution of groundwaters occurs. While this recommended approach will require a substantial increase in landfill disposal fees for those who generate the waste, in the long term, since groundwater pollution will be avoided, it will be cheaper.

The Importance of the Three Rs

The importance of practicing recycling of municipal solid waste and industrial solid waste to the maximum extent practicable in order to minimize groundwater pollution by Subtitle D or equivalent landfills has been reviewed by Lee and Jones-Lee (2000). Reuse, reduction and recycling of wastes significantly reduces the amount of wastes that need to be landfilled and, therefore, conserve natural resources and enhance environmental protection.

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