Overview of Landfill Post-Closure Issues[1]

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Abstract

Municipal solid waste landfills and industrial "non-hazardous" and hazardous waste landfills contain waste components that represent significant threats to public health and the environment. These threats are manifested in the release of leachate to groundwater and in some instances surface water systems and through sub-soil surface and landfill cover migration of landfill gases. For most landfills, the waste components represent a threat to public health and the environment effectively forever. In an attempt to "control" these threats, regulatory agencies at the federal and state level have adopted a "dry tomb" landfilling approach in which the wastes are enclosed in plastic sheeting (FML) and compacted soil (clay) liners and covers. An overview discussion is presented of the deficiencies in the "dry tomb" landfilling approach in providing public health and environmental protection from landfill releases in the post-closure period for as long as the wastes represent a threat. Included is a discussion of landfilling approaches that will address these deficiencies and not significantly change the overall cost of management of municipal and industrial solid wastes.

Key Words: landfill, closure, groundwater pollution, landfill gas, Subtitle D

Introduction

In the US MSW and industrial solid waste are largely managed by landfilling. A brief review of the problems associated with MSW landfilling are presented below. Additional information and references to the literature providing further discussion of the issues summarized herein are provided in the reference list for this paper.

Leachate Pollution of Groundwater. Historically, municipal and industrial landfills have commonly caused localized, adverse impacts to public health and the environment through releases of leachate and landfill gas. Jones-Lee and Lee (1993) and Lee and Jones-Lee (1994a) have industrial hazardous and non-hazardous waste landfill leachates contain a variety of hazardous or otherwise deleterious chemicals that can cause groundwaters to become unsuitable for use as a domestic water supply source. While current federal regulations under RCRA focus on the control of so-called hazardous components in leachate, there are large amounts of unregulated (non-conventional) pollutants and conventional pollutants in MSW leachate that can render a groundwater unusable for domestic water supplies or many other purposes.

Landfill Gas Problems. Landfill gas (CH_4 and CO_2) represents personal safety hazards due to explosions and damage to vegetation. Further, landfill gas contains a variety of volatile

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hazardous chemicals that are significant threats to public health and animals. Some of the methods for managing landfill gas, such as flaring, are now being found to develop additional hazardous substances, such as dioxins, in the flare (Eden, 1993).

There are several tens of thousands of landfills in the US that are polluting the groundwater system, soil and atmosphere near the landfill through landfill releases that are not being adequately controlled today. Most of these landfills are inactive (no longer accepting wastes). Attempts are being made in some areas to develop closure approaches that are designed at least for a period of time to reduce the rates of emission of leachate and landfill gas. As discussed below, there are significant questions about the efficacy of the approaches being followed in closing inactive landfills.

Subtitle D Landfills. Landfills permitted under current US EPA Subtitle D regulations require the development of closure plans that will minimize at least for a period of time (30 years?) the releases of leachate and landfill gas from the landfill. There are also, however, significant questions about the ability of the landfills permitted under Subtitle D to provide true long-term public health and environmental protection from some of the waste-derived constituents for as long as the wastes in the landfill will be a threat.

It is important to note, as discussed by Jones-Lee and Lee (1993) and Lee and Jones-Lee (1994a,b), that Subtitle D does not require the protection of groundwater from impaired use by landfill-derived constituents. As implemented by the US EPA in accord with the requirements set forth in RCRA, Subtitle D only addresses the control of a limited number of potentially hazardous chemicals that are present in MSW and does not address the large numbers and amounts of non-conventional, unregulated pollutants and conventional pollutants found in municipal and industrial landfill leachates.

According to the US Congress General Accounting Office, there are about 60,000 chemicals in commerce in the US today. Many of these could be present in MSW leachates and in some industrial non-hazardous and hazardous solid waste leachates. Only about 200 of the 60,000 chemicals are regulated today. As discussed by Jones-Lee and Lee (1993), it should never be assumed, as is often done in implementing RCRA Subtitle C and D, that because a groundwater that has been polluted by municipal and/or industrial solid waste leachates meets current drinking water MCL's (Maximum Contaminant Levels) that the water is safe to consume.

The key to long-term public health and environmental protection from landfill releases from currently active and inactive landfills is the development of appropriate closure approaches and post-closure maintenance - activities. A review of the problems with currently used closure procedures is presented below.

Closure of Inactive Landfills

There are an estimated over 50,000 inactive MSW landfills in the US today. It is estimated that about 75-80% of these are now polluting groundwaters. In California there are over 2,200 active and inactive MSW landfills. The State Water Resources Control Board has found that 83% of these are currently polluting groundwater with MSW leachate. Groundwater pollution by inactive dumps and municipal solid waste landfills is a very significant cause of groundwater quality deterioration that is not now being adequately addressed at the federal and state levels.

The typical inactive landfill is in an area of low-value land, sometimes with a high groundwater table. The landfill was operated as a dump in which there was little or no attempt to control leachate and gaseous emissions from the landfill. When the dump stopped receiving wastes a layer of dirt was placed over the top of the dump. Leachate and landfill gas emissions are commonly occurring at these types of landfills.

Sanitary Landfilling. Beginning in the 1950's in some areas, states developed landfilling regulations that required that the landfilling be done by sanitary landfilling technology. The sanitary landfill was designed to control to some extent, but not necessarily adequately, some of the adverse impacts associated with landfilling of MSW in a dump. The principal difference between a sanitary landfill and a dump was that each day's wastes were supposed to be covered by a few inches of soil. This soil layer reduced the odorous emissions from the landfill associated with the previously deposited waste. It did not address, however, the odors emitted from the wastes during the dumping and until the wastes are covered.

The soil layer also reduced to some extent the ability of vermin, such as birds and rodents, and disease vectors, such as birds, rodents, insects (flies), etc., to gain access to the waste. However, because of the cost of the soil layer and inadequate regulatory attention, it is the authors' experience that many sanitary landfills received less than the typically prescribed six inches of daily cover over the day's waste deposition.

Landfill Gas Management. When the landfill became inactive, an additional foot or two of soil was placed on top of the landfill. In the typical inactive sanitary landfill or dump no attempt is made to control leachate generation and release from the landfill to the groundwater system. Further, with few exceptions, limited efforts have been made to control landfill gas emissions from inactive dumps or sanitary landfills. The exceptions to this are situations where the landfill gas migration below the soil surface represents potential explosive hazards to those who use structures near the landfill where the gas could accumulate within the structure above the lower explosive limit (about 5% $CH4$). In those situations, the inactive dump or sanitary landfill would include a landfill gas collection system with gas-collecting wells and plumbing designed to some extent, at least for a limited period of time, to collect landfill gas and flare it.

In a limited number of instances, the collected landfill gas would be used for energy production. Generally, the quality of landfill gas and the rate of production are such that it is not economically feasible to use landfill gas as a significant source of energy. Natural pipeline gas is of much higher quality and sufficiently inexpensive to limit the use of landfill gas.

It is the authors' experience that landfill gas collection systems for inactive dumps or sanitary landfills are rarely adequately maintained so that the system reliably collects the landfill gas being emitted. Of particular concern is the maintenance of the landfill gas collection plumbing to maintain its design characteristics. Differential settling within the landfill wastes puts high stress on the plastic pipe that is often used in landfill gas collection systems that can lead to breaks or cracks in the pipe. Further, the differential settling can lead to low spots in the pipe where landfill gas condensate and/or infiltrating moisture that accumulate in the pipe can block gas transport through the pipe.

Another important problem with gas collection systems in inactive dumps and sanitary landfills is that large cracks can develop in the surface soil layers due to differential settling, desiccation cracking, etc. that will allow transport of landfill gas through the cracks. In general today, except for a short period of time after installation of a gas collecting system at an inactive landfill, the systems fail to function as designed and are often not adequately maintained.

The current approach for closing inactive landfills typically involves the installation of a gas collection system and the installation of a low-permeability cover. The gas collection system is designed to prevent offsite migration of gas and thereby eliminate explosions in adjacent property structures. Thus far, limited attention has been given to controlling subsurface landfill gas migration to protect public health and wildlife from the hazardous chemicals present in landfill gas. Additional attention will likely be given to controlling landfill gas emissions from inactive landfills due to the significance of CH_4 as a greenhouse gas. Thorneloe (1994) has discussed the importance of inactive municipal solid waste landfills as a source of CH_4 that contributes to the greenhouse gas problem.

Compacted Clay Layers in Covers. The low-permeability layer of soil that is required in the closure of inactive landfills is designed to reduce moisture entrance into the landfill and thereby minimize leachate generation. This low-permeability layer, however, is not designed and rarely adequately maintained to keep moisture from entering the landfill through the cover. Compacted clay layers in landfill covers are well-known to experience a wide variety of problems that prevent them from being effective in controlling moisture entrance into the landfill for even short periods of time after construction, much less for as long as the wastes in the landfill will be a threat (Daniel, 1990; Daniel and Koerner, 1991).

Often the low-permeability layer of a landfill cover is located below a topsoil layer of one to two feet thick and a drainage layer of a foot or so in thickness. This arrangement is appropriate to minimize erosion of the low-permeability clay layer and to allow water that passes through the topsoil layer that is needed to keep the vegetation on this layer alive as an erosion barrier to drain off the low-permeability layer through the drainage layer. The one to several feet of material above the low-permeability layer, however, precludes effective inspection of this layer to detect desiccation and differential settling cracks that occur in this layer.

The studies of Montgomery and Parsons (1994) have demonstrated the severity with which cracking of a low-permeability layer landfill cover can occur in a short period of time. They observed cracks up to one-half inch wide that extended several feet into a compacted clay cover. These cracks were present after a couple of years after cover construction. They would not necessarily be visible from the surface of the cover since they are not transmitted through the drainage layer and topsoil layer of the cover. This situation means that the normal approach advocated for maintenance of the landfill cover of visual inspection of the topsoil layer with backfilling of any cracks that are observed with soil will be highly ineffective in preventing moisture from entering the landfill through cracks in the low-permeability layer.

FMLs in Covers. An alternative approach for the construction of a landfill cover is the use of a flexible membrane liner (FML) in the cover as the low-permeability layer. While FMLs if properly designed, installed and protected from puncture can provide a low-permeability layer that can be highly effective in preventing moisture from passing through it, they are subject to a number of problems that require considerable attention. It is generally acknowledged that FMLs are better able to stand stress associated with differential settling; they are not immune to stress cracking, however. Over time an FML low-permeability layer in a landfill cover, even if designed and constructed to prevent moisture from entering the landfill at the time of construction, will develop holes, cracks or other areas where moisture will be able to enter the wastes and generate leachate. (See references to Lee and Jones-Lee for additional discussion of these issues.)

The FMLs, like the low-permeability clay layers used in landfill covers, will be buried below several feet of topsoil and a drainage layer and therefore will not be subject to visual inspection for problems that develop in the FML. As discussed below, however, landfill cover leak detection systems are now available to detect when the FML loses its integrity. Such systems provide an opportunity to maintain a landfill cover so that it will prevent moisture from entering the landfill and generating leachate.

<u>Groundwater Monitoring</u>. Another component of the current approach for closure of inactive landfills and dumps is the installation of a groundwater monitoring system based on vertical monitoring wells located down groundwater gradient from the landfill. At the locations where leachate-contaminated groundwater is found in the monitoring wells, a pump and treat groundwater extraction program may be implemented. Such systems are typically designed to prevent the further spread of leachate-contaminated groundwaters. Further, such systems can be effective in cleaning up the groundwater and aquifer to reduce the threat that the leachate-contaminated groundwater and aquifer represent to groundwater quality. It is generally recognized today, however, that once contaminated by MSW and many other types of landfill leachate, that part of the aquifer will never be usable again as a domestic water supply source because of the inability to effectively remove all of the pollutants from the aquifer solids.

For landfills located in areas with fractured rock, limestone or highly complex groundwater systems hydraulically connected to the landfill, the ability to reliably detect the leachate-polluted groundwater with vertical groundwater monitoring wells is limited. Further, it is far more difficult to develop an effective pump and treat system to prevent the further spread of leachate-contaminated groundwaters in complex hydrogeologic areas.

The authors have experienced situations where landfill owners and/or regulatory agencies will claim that an inactive, or for that matter, active, unlined landfill is not polluting groundwater. Such statements are frequently based on the fact that thus far no leachate had been detected in the groundwater monitoring wells downgradient of the landfill. In some situations however, the transport of leachate through a deep unsaturated zone and the slow movement of the groundwater under the landfill significantly delays when the groundwater pollution that is occurring by unlined or compacted soil lined landfills is detected in groundwater monitoring wells. There will be few dumps and sanitary landfills or compacted soil lined landfills, such as those that are discussed below that have been permitted in California during the period 1984 through 1993, that will not at some time in the future pollute the groundwater system associated with the landfill. Since there are few landfills sited at geologically suitable sites where the properties of the geological strata underlying the landfill will prevent leachate from migrating through it for as long as the wastes are a threat, i.e. forever, it is appropriate to assume that every inactive dump or sanitary landfill is now or will at some time in the future pollute groundwaters in the vicinity of the landfill by landfill leachate.

Unsaturated Zone Monitoring. In order to protect groundwater resources as much as possible, it is recommended that every unlined landfill or compacted soil lined landfill owner be required to construct an array of horizontally drilled sampling locations under the landfill. These should be located in such a way as to have a high probability of detecting leachate transport through the unsaturated zone before groundwater pollution occurs. Keller (1994) has described the use of a SEAMIST system for detecting groundwater pollution by landfill leachate in the unsaturated, as well as saturated, zone under the landfill. The adoption of such an approach can lead to considerable improvement in groundwater quality protection from inactive dumps and sanitary landfills, as well as active sanitary landfills and Subtitle D landfills.

High Watertable Problems. There are situations where solid waste dumps and sanitary landfills were sited in which the wastes are located below the watertable. Under these conditions, leachate can be generated due to groundwater moving into the wastes. While it may be possible to artificially lower the groundwater table in the vicinity of the landfill through pumping and thereby prevent groundwater from generating leachate, such approaches would require pumping effectively forever if leachate generation in the landfill is to be prevented.

Leachate Generation in Arid Areas. There are some who mistakenly claim that landfills located in arid areas do not generate leachate. Such claims are frequently based on an inappropriate water balance analysis for the landfill in which the net annual water flux for the landfill is calculated. Typically in arid areas the net annual water flux direction is from the surface layers of the soil to the atmosphere. However, even areas which on the average only receive a couple of inches of rain per year do experience periods of time in which large amounts of rainfall occur in a short period of time. During this time there is significant transport of the precipitation that occurs on the surface of the soil to the groundwaters of the area.

Examination of the groundwater pollution records (see State Water Resources Control Board SWAT reports) near MSW landfills located in desert regions shows that with very few exceptions, these landfills do generate leachate and pollute groundwaters. While the amount of leachate generated in landfills located in such areas will be less than the amount developed in wetter areas, it can be a highly significant cause of groundwater pollution.

Unsaturated Leachate Transport. Another mistake that is frequently made in analyzing the potential for an MSW landfill to cause groundwater pollution in arid areas is the assumption that the moisture-holding capacity of the wastes has to be exceeded before leachate generation occurs. Such an approach ignores the unsaturated transport of leachate-derived constituents within the wastes and in the aquifer system above the watertable. Transport of MSW-derived solid waste components can readily occur in the wastes and in the aquifer without exceeding the moisture-holding capacity of the wastes associated with unsaturated transport.

Impediments to Closure of Inactive Landfills. The magnitude of landfill closure costs, often several hundred thousand dollars per acre, are sufficient that unless the local regulatory agencies aggressively enforce regulations, private and especially public owners of inactive landfills will not initiate "proper" closure of the landfill so that there is effective landfill gas control and minimization of further leachate generation.

A significant factor in controlling the pollution of groundwaters by MSW leachate is the will of the regulatory agencies to require that landfill owner - operators initiate pump and treat systems. Such systems are expensive to construct and, most importantly, they may have to be operated for a very long time, effectively forever. This is especially true in situations where continued leachate generation will occur due to the inability of the landfill owner to install and maintain a cover on the landfill that will prevent moisture from entering the wastes. The authors have repeatedly observed that regulatory agencies, even with full regulatory authority to require a public or private landfill owner to initiate actions which will prevent further spread of leachate-contaminated groundwater, are reluctant to use this authority even when the groundwaters have been contaminated by highly hazardous chemicals. Since in some instances the spread of a leachate plume from a landfill occurs at the rate of one to two feet per day, very large amounts of groundwaters can be rendered unusable for domestic water supply purposes in a relatively short period of time as a result of either inadequate monitoring of the leachate plume arising from an inactive dump or landfill, lack of regulations which require clean-up of MSW leachate-contaminated groundwaters when found or the lack of will on the part of the regulatory agencies to enforce the regulations that require such clean-up. It is for this reason that many of the tens of thousands of inactive MSW landfills that exist in the US continue to pollute groundwaters in the vicinity of the landfill.

Post-Closure Care Funding. In order to implement proper closure of inactive dumps and sanitary landfills, it will be necessary to develop a revenue source to provide and maintain at least a low-permeability and preferably, at some locations where it is not possible to reliably develop a pump and treat system for leachate-contaminated groundwater, an impermeable cover. Further funds will be needed to operate pump and treat systems for leachate- polluted groundwaters near the landfill. It is suggested that the best way to fund these activities is to increase the current disposal fees for the people in the area from which the inactive landfill received its waste. These fees would be placed in a dedicated trust that would be of sufficient magnitude and would exist in perpetuity to meet plausible worst-case scenario needs for stopping further groundwater pollution by the landfill and for the management of landfill gas.

The trust fund should be of sufficient magnitude in 10 years or so to mine the wastes in the landfill, to recover recyclables and, most importantly, to stop further groundwater pollution. Lee and Jones (1990) have discussed the use of landfill mining as a method of stopping groundwater pollution by an existing landfill. As they indicate, landfill mining can be highly effective in providing additional landfill capacity in a region and, most importantly, it can stop/prevent pollution at existing landfills.

Closure of Active Landfills

In the 1980's some states adopted compacted soil and/or FML-based liner systems. Since 1993 all states have had to use the minimum Subtitle D composite liner. These approaches present significant problems for providing public health and environmental protection for as long as the wastes in the landfill represent a threat. A review of these issues is presented below.

Compacted Soil Liners. Since 1984, the California State and Regional Water Quality Control Boards have been permitting MSW landfills which have only one foot of compacted soil with a permeability no greater than 10-6 cm/sec at the time of construction. While this is the minimum design standard allowed under Chapter 15 regulations, it obviously does not conform to the overall performance standard set forth in these regulations of preventing impairment of use of groundwater by landfill leachate and/or landfill gas for as long as the wastes in the landfill represent a threat. A simple Darcy's Law calculation will show that the minimum liner design specified in these regulations will be breached within a few years after installation by landfill leachate.

Composite Liners. In 1993 the US EPA required that sanitary landfill owners install at least a single composite liner. However, it is now widely acknowledged that a single composite lined landfill, conforming to minimum Subtitle D design requirements, will at best only postpone for a few decades when groundwater pollution occurs at the landfill. Even if proper design, construction and operation of the landfill is achieved so that the FML in the Subtitle D composite liner is intact without holes which would rarely be the case, it is only a matter of time until the plastic sheeting component of the composite liner will be an ineffective barrier to leachate transport through the liner (See Lee and Jones-Lee references).

The inclusion of an FML in the landfill liner, while potentially retarding when groundwater pollution occurs, makes the monitoring of liner failure using vertical monitoring wells spaced hundreds to a thousand or so feet apart at the point of compliance for groundwater monitoring at the landfill highly unreliable. Cherry (1990) first pointed out that the initial leakage through FMLs will generate finger-like plumes from holes, rips or tears that occur in the liner. These finger-like plumes will typically be no more than five to ten feet wide at the point of compliance. With groundwater monitoring wells with zones of capture of about one foot on each side of the well, it is obvious that the initial failure of the liner due to inadequate construction and/or inappropriate placement of wastes within the landfill, which results in developing holes in the FML, will not be detected. This is one of the reasons why there are few documented cases of liner failure at Subtitle D landfills. As discussed by Lee and Jones-Lee (1994c), the groundwater-based monitoring system that was adopted by the US EPA in many states provides a very low reliability for detecting landfill liner failure before widespread groundwater pollution occurs.

Adequacy of Subtitle D Closure Requirements. The closure of MSW landfills permitted under Subtitle D requires that the owner - operator develop closure plans and funding to close the landfill in accord with current regulatory requirements. However, the current regulatory requirements fall far short of providing reasonable assurance that today's Subtitle D landfills will not result in significant pollution of the environment by landfill leachate and gas.

The US EPA, as part of implementing Subtitle D, required that MSW landfills be of a "dry tomb" type where there is an attempt to use plastic sheeting and/or compacted soil-clay to isolate the wastes from water that can generate leachate and that promotes the generation of landfill gas, i.e., create a "dry tomb." The single composite liner allowed in Subtitle D landfills will not prevent groundwater pollution for as long as the wastes represent a threat. The monitoring systems that have been developed in Subtitle D landfills based on detecting leachate in groundwater are highly unreliable for preventing widespread groundwater pollution. Further, the current post-closure funding which provides for minimal funding of post-closure activities, such as removal of leachate that accumulates in the leachate collection and removal system sump, operation and maintenance of a gas collection system, groundwater monitoring and limited superficial cover maintenance for a mandatory period of 30 years after closure, are all highly inadequate to protect public health and the environment. Alternative approaches for "dry tomb" - Subtitle D landfilling are discussed below that will protect public health and the environment at a small additional cost to those who generate the waste of a few cents per person per day more than is being paid now for MSW management.

<u>Landfill Gas Production in "Dry Tomb" Landfills</u>. The construction of "dry tomb" type landfills has important implications for influencing the pattern of landfill gas production. Typically in the classical sanitary landfill, the maximum rate of landfill gas production occurs a few years after the landfill is put in service. Gas production continues for several decades, often for 30 to 50 years after closure of the landfill. This pattern was the origin of the minimum 30-year post-closure care that was adopted by the US EPA as part of implementing RCRA. As discussed by Lee and Jones-Lee (1992, 1993a), those responsible for selecting that period, however, made a significant error where they confused landfill stabilization, i.e. the cessation of landfill gas production, with landfill leachate production. While the two are somewhat interrelated in that they are both dependant on moisture, and landfill gas production will effectively cease 30 to 50 years after closing a classical sanitary landfill, landfill leachate production can continue for a thousand or more years where the leachate derived from moisture entering the landfill will be a significant threat to groundwater quality. Belevi and Baccini (1989) have estimated that classical sanitary landfills in Switzerland will still be leaching lead at concentrations above drinking water standards 2,000 years after closure.

The minimum 30-year post-closure care specified in RCRA and Subtitle D is based on erroneous assumptions about the behavior of landfills and is highly misleading. This creates a situation in which there are significant questions about whether adequate funds will, in fact, be available 30 years after closure of Subtitle D landfills to meet the needs associated with controlling landfill gas production and leachate generation for as long as the wastes represent a threat.
Landfill gas production in Subtitle D landfills will be altered significantly from the pattern typically found for classical sanitary landfills. The rate of gas production in classical sanitary landfills is moisture limited. As additional moisture is added to the landfill, such as with leachate recycle, additional gas production is experienced. Christensen and Kjeldsen (1989) have reported a linear relationship between rates of gas production and moisture in MSW up to about 90% of waste saturation; below about 10% moisture, the gas production rate becomes very slow. It is possible that if a true low-permeability cover for a "dry tomb" landfill is achieved, that gas production will cease until inadequate cover maintenance is experienced. This, coupled with the

practice of burying MSW in plastic bags that are not shredded, will greatly extend the period over which landfill gas production will occur in "dry tomb" type landfills beyond the 30 years that is planned for in Subtitle D regulations.

Suggested Approach for Landfill Design and Closure

As long as "dry tomb" type landfills are constructed for MSW management, it will be necessary to design, construct, operate and especially close these types of landfills to properly consider the inevitable failure of the landfill waste containment system (liners) (Lee and Jones-Lee, 1993b).

Suggested Approach for Liner Leak Detection. As discussed by Lee and Jones-Lee (1994c), the unreliability of using vertical monitoring wells spaced more than a few feet apart at the point of compliance for groundwater monitoring at Subtitle D landfills requires that a different monitoring approach be used. They suggest that the approach that has been adopted by the state of Michigan should be used in which a double composite liner is used, where the lower composite liner is a leak detection system for the upper composite liner. When leachate is detected in the leachate detection system between the two composite liners, the landfill owner/operator should within a short period of time (a few months) be able to stop the passage of leachate through the upper liner. If this cannot be accomplished or is not done, then the landfill containment system must be determined to have failed, and the wastes have to be removed from the landfill and properly managed. This approach recognizes the inevitable failure of the lower composite liner to prevent leachate from passing through it for as long as the wastes represent a threat, i.e. forever.

Leak-Detectable Covers. "Dry tomb" landfill owners may significantly or potentially ad infinitum extend the life of a "dry tomb" landfill storage of waste by constructing a leak detectable cover on the landfill. There are two systems that show promise in providing a reliable leak detection system in landfill covers; both employ FMLs. The Robertson System (1990) consists of a double FML separated by a geogrid that are seamed together around the edges in quarter- to half-acre panels. A vacuum is applied to these panels. When the vacuum can no longer be maintained, i.e. there is a hole in one of the FML sides of the panel, the panel can be uncovered and the leak found and repaired.

A new liner leak detection system has been announced by Gundle Lining Systems, Inc. which is based on the work of Nosko and Andrezal (1993). A series of electrical sensors are placed on each side of an FML, and electrical current is applied. The sensors detect any abnormalities in the current fields. Through data analysis of the response of the sensors it is possible to detect the location of the leak in the FML. While this system is intended to detect leaks associated with the construction of the liner and placement of waste in the landfill, this approach cannot be reliably used to detect the long-term eventual failure of the FML in the landfill liner since inevitably the sensor system will malfunction due to failure of the insulation on the electrical wiring, etc. This approach, however, has a significant potential applicability for developing a leak detectable cover for "dry tomb" landfills where periodically the FML and sensor systems could be replaced when they fail to function properly.

Funding Closure and Post-Closure Care. The key to the long-term satisfactory operation of a "dry tomb" landfill is the availability of funds that can be used as long as the landfill exists to operate the leak detection system in the cover, and to repair as necessary the low-permeability layer of the cover and the leak detection system. The funding that is now provided for closure of Subtitle D landfills is grossly inadequate compared to the funding that will be needed to ensure that adequate funds will be available when needed to meet all plausible worst-case scenarios that could occur associated with a particular landfill, including waste exhumation, treatment and reburial of the treated residues that cannot be recycled.

Lee and Jones-Lee (1992, 1993c) have discussed the myth that post-closure funding will only be needed for 30 years after closure. They have also pointed out that a dedicated trust fund derived from additional disposal fees of a few cents per person per day for the waste placed in the landfill can generate a sufficient fund at most landfills to provide funding needed for "dry tomb" landfill post-closure maintenance and eventual waste exhumation and treatment. The dedicated trust fund derived from disposal fees is recognized as a potentially reliable funding mechanism to ensure that the necessary post-closure funds will be available when needed. All other financial instruments that are allowed today under RCRA Subtitle D have potentially significant problems in ensuring that funds will be available when needed for post-closure care. (See Lee and Jones-Lee references.)

Closure of Subtitle D Landfills. One of the issues that needs to be addressed is how should Subtitle D landfills that only have a single composite liner be closed? Because of the virtual impossibility of detecting liner failure before widespread groundwater pollution occurs associated with plastic sheeting lined landfills, it is recommended that all Subtitle D landfill owners be required to install a network of sampling probes under the landfill that are designed to detect with a high degree of reliability failure of the composite liner to prevent leachate from passing through it. Keller (1992) has described a monitoring system that can be installed under existing landfills through the use of horizontal drilling that can detect with a high degree of reliability landfill liner failure in the unsaturated zone. Systems of this type should be installed under all Subtitle D landfills that utilize a single composite liner in order to detect liner failure before widespread pollution occurs. When liner failure is detected where leachate passage through the liner cannot be stopped, then the waste must be removed from the landfill if the groundwater resources of an area are to be protected from pollution by landfill leachate.

Summary

Today significant problems exist with current regulatory approaches covering closure and post-closure activities for inactive dumps and sanitary landfills and Subtitle D landfills. The approach adopted for closure and post-closure care of Subtitle D landfills permitted under RCRA, at best, only postpones when significant public health and environmental problems will occur at most "dry tomb" landfills. If public health and environmental protection is to be achieved for as long as the wastes present in these landfills will be a threat, liner leak detection based on a double composite liner system should become standard design for all "dry tomb" type landfills. Further, it should be recognized that the leakage of leachate through the upper composite liner that cannot be stopped represents liner failure which requires waste exhumation.

All "dry tomb" type landfills should contain an FML cover with a leak detection system that can determine when holes occur in the FML. When they are found, then the area of the cover where they are located should be exposed through removal of the top soil and drainage layer so that the cover can be repaired. As necessary the leak detection system and the FML will need to be replaced to ensure that they do, in fact, prevent moisture from entering the waste.
Since "dry tomb" landfills will have a high demand for funding for post-closure maintenance and monitoring for as long as the landfill exists, it will be necessary to establish a much more reliable and adequate funding approach than that typically used today for Subtitle D type landfills. A dedicated trust derived from disposal fees of sufficient magnitude to meet all plausible worst-case scenario failures and monitoring - maintenance needs should be developed.

It should be understood that post-closure activities will be needed for as long as the landfill exists. If at any time there are inadequate funds to prevent leachate generation within the landfill, then those responsible for the landfill should be required to exhume the wastes, properly treat them, and bury any non-recyclable treated residues.

In order to fund post-closure care activities for inactive dumps and sanitary landfills it will likely be necessary to develop a dedicated trust fund from disposal fees from currently active landfills in the region to properly close and maintain the impermeable covers and associated leak detection system as well as to operate and maintain the pump and treat system that will have to be installed at many inactive dumps or sanitary landfills if further groundwater pollution by leachate is to be controlled.

Adoption of these approaches will provide a potentially viable mechanism by which past and current MSW management by landfilling can, in the case of inactive dumps and sanitary landfills, prevent further groundwater pollution by landfill leachate. For Subtitle D landfills constructed with either a single or double composite liner, it will provide a mechanism for preventing groundwater pollution by landfill leachate.

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Overview of Landfill Post-Closure Issues

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Problems with Current Approaches for MSW Landfill Closure and Post-Closure

Suggested Approaches for Closing Classical Sanitary Landfills and Subtitle D Landfills to Provide Groundwater Quality Protection for as Long as Wastes Are a Threat

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Presented at ASCE national conference on Landfill Closure, San Diego, CA October, 1995

Landfilling Approaches

City/County Dumps
- Open pit, Burning

Sanitary Landfills
- Open Dump with Daily Cover to Control Impacts of Waste Management and Deposition *to Some Extent*
- No Consideration of Groundwater Pollution Even Though Well-Known Since 1950's That MSW Landfills Cause Groundwater Pollution - ASCE Sanitary Landfill Manual

Subtitle D RCRA Landfills
- "Dry-Tomb" Approach
- Wrap Garbage in Plastic Sheeting (FML) and Compacted Soil/Clay, i.e., Single Composite Liner

Potential Problems with Landfilling of Wastes
◂ Landfill Emissions ▸

Landfill Gas
- Safety-Explosion
- Hazardous Gases - VOC's
- Odors
- Public Health and Nuisance

Leachate - Garbage Juice
- Wide Variety of Hazardous and Otherwise Deleterious Chemicals
  - Conventional Chemical Pollutants
    - Fe, Mn, TDS, Hardness, H_2S, Taste and Odors, etc.
  - Priority Pollutants
    - Human Health Impacts - VOC's, Metals, Etc.
  - Non-Conventional Pollutants
    - 95% of Organics Present Not Identified and Regulated
    - 60,000 Chemicals in Use; ~200 Regulated
      - New Hazardous Chemicals Being Identified
      - e.g., Crotonaldehyde

US EPA Subtitle D
"Dry Tomb" Landfilling Approach

- Site Landfill at Any Location
- "Isolate" Waste from Moisture That Generates Leachate
  Line Landfill with Thin Plastic Sheeting (FML)
- Collect and Remove Leachate Generated in Landfill with a Single Composite Liner
- Provide for Post-Closure Maintenance and Monitoring for at Least 30 Years
- Groundwater Monitoring Wells Spaced 100's to 1,000+ ft Apart to Detect Liner Leakage That Causes Groundwater Pollution

"Dry Tomb" Landfills
◂ Realities ▸

"Dry Tomb" Landfilling Approach Fundamentally Flawed if Groundwater Quality Protection Is Expected for as Long as the Wastes Are a Threat

MSW in "Dry Tomb" Landfill Will Be a Threat to Groundwater Quality Because of Leachate Generation **Forever**

Will US EPA Subtitle D "Dry Tomb" Landfilling Approach Prevent Groundwater Pollution by Landfill Leachate for as Long as Wastes in Landfill Are a Threat? Not likely.

Problems with Subtitle D Landfilling Approach
◂ Composite Liner System ▸

Composite Liner System Will Not Function as Effective Leachate Collection System for as Long as Wastes Are Threat to Produce Leachate

US EPA (Aug 30, 1988) *Federal Register* - Proposed Subtitle D Regulations

"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."

US EPA Criteria for Municipal Solid Waste Landfills (July 1988)

"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."

(continues)

Problems with Subtitle D Landfilling Approach
◂ Composite Liner System ▸
(continued)

Haxo and Haxo (1988)

"The polymers that were discussed and first-grade compounds based on these polymers should maintain their integrity in landfill environments for considerable lengths of time, probably in terms of 100's of years.

Nevertheless, when these polymers or compounds are used in products such as FMLs, drainage nets, geotextiles, and pipe, they are subject to mechanical and combined mechanical and chemical stresses which may cause deterioration of some of the important properties of these polymeric products in shorter times."

"The combined mechanical and chemical stresses under which the liner system functions may cause cracking and breaking of the components due to environmental stress-cracking or possibly to mechanical fatigue under long service."

(continues)

Problems with Subtitle D Landfilling Approach
◂ Composite Liner System ▸
(continued)

Haxo and Haxo (1988) (continued)

"Seams of FMLs continue to be an area of concern, as none of the test methods truly assess the effects of long-term exposure in landfills."

* * *

"Clogging of drainage and detection systems continues to present a problem. The clogging can be by biological clogging due to growth of sedimentation or through precipitation of dissolved constituents."

Subtitle D Landfill Cover
◂ Will Not Keep Wastes Dry ▸

FML Buried below Top Soil and Drainage Layer
Not Subject to Inspection

Leaks Will Develop in Final Cover
Allow Leachate Generation

Subtitle D Groundwater Monitoring for Liner Leakage

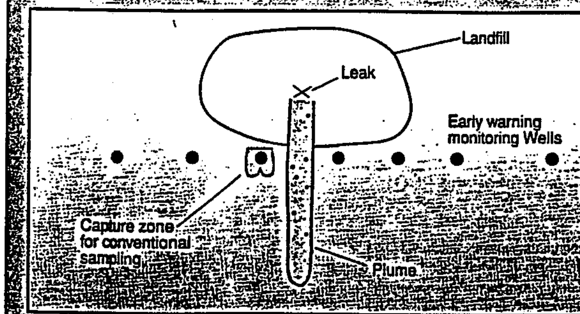
Leak Detection System Not Reliable for Detection of Leakage of Composite Liner before Widespread Groundwater Pollution Has Occurred

A Groundwater Protection Strategy for Lined Landfills

G. FRED LEE   ANNE JONES-LEE

EPA's groundwater monitoring program, ostensibly designed to detect failure of landfill liners for Subtitle C (hazardous waste) and Subtitle D (municipal solid waste) waste management facilities, does not support reliable early detection of groundwater pollution. A significantly different approach is needed to address the fundamental flaws in the design of the EPA program, which is being adopted by states to detect leakage from lined landfills. This strategy would utilize a leak detection system within the landfill liner and would require a reliable source of funds for the inevitable need for exhumation of landfill wastes once a leak is detected.

FIGURE 1
Pattern of landfill leakage—Groundwater contamination from lined landfills



After Cherry, 1990.

As shown in Figure 1, the nature of incipient leakage from a lined landfill is significantly different from that from an unlined landfill. The groundwater monitoring programs used today for lined landfills presume that the leachate plume develops across the landfill and moves in a wide front in the groundwater. However, initial leakage from a lined landfill will be from point sources—holes, tears, imperfections—in the liner system. Those point sources will produce leachate-contaminated groundwater plumes that move as fairly narrow "fingers" with limited lateral spread in the distance between the landfill and the point of compliance for groundwater monitoring (*1*). Because of the limited zone of capture of conventional vertical monitoring wells (about 1 ft), their wide spacing, and the nature of incipient leakage, the current practice of groundwater monitoring at lined landfills is cosmetic and of little utility in protecting groundwater resources from pollution by leachate.

A reasonable requirement for a groundwater monitoring system is that it demonstrate at least a 95% probability of detecting the incipient presence of leachate-polluted groundwaters at the point of compliance for the monitoring system. Although it is technically feasible to implement that performance requirement with a "picket fence" of vertical monitoring wells spaced a few feet apart along the downgradient, the cost would be high.

A permanent threat

Hazardous waste and municipal solid waste dry-tomb landfills represent an ongoing threat to groundwater quality. Because the plastic sheeting used in the composite liners in Subtitle C and D landfills will eventually deteriorate, and because there is virtually no possibility that landfill covers of the type being constructed today will keep moisture out of the landfill for as long as the wastes represent a threat—that is, forever—it is inevitable that leachate will migrate through the liner to pollute the underlying groundwater.

At best, groundwater monitoring detects leachate pollution after the fact. In areas where groundwater could be used for domestic or any other purposes, the presence of Subtitle C and D landfills represents a continuing threat unless an approach is implemented and maintained to provide appropriate intervention before leachate can reach the groundwater. Thus, instead of

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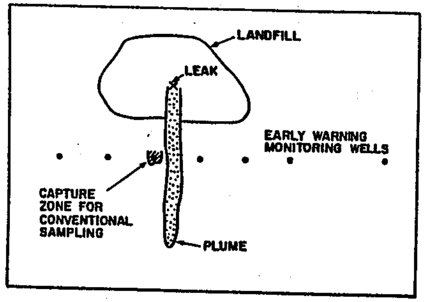
Pattern of Landfill Leakage - Groundwater Contamination from Lined Landfills
(After Cherry, 1990)



Post-Closure Care Funding

Only 30 yrs of Post-Closure Care Funding Required; May Be Extended

Inadequate Funding Level for 30 yrs after Closure

No Assurance That Adequate Funds Will Be Available for as Long as Wastes in Landfill Are Threat

Some Financial Instruments Used Not Reliable

LANDFILLING OF SOLID & HAZARDOUS WASTE: FACING LONG-TERM LIABILITY

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Proceedings of the 1994 Federal Environmental Restoration III & Waste Minimization II Conference, Hazardous Materials Control Resources Institute, Rockville, MD, pp. 1610-1618, April (1994).

ABSTRACT

In the past, the "cheapest" method available was used for the management of solid "non-hazardous" and "hazardous" waste. Now with "cradle-to-grave" liability, many companies are more critically evaluating the near-term and long-term liabilities and costs associated with various options for solid and liquid waste management. Recycle and reuse of wastes with residue management that eliminates long-term liability are the most desirable. However, most waste management programs involve some landfilling of wastes and/or treated residues. While claims are made about the environmental protection afforded by "modern" landfills of the type prescribed by the US EPA in Subtitles C and D for "hazardous" and "non-hazardous" wastes, the technical deficiencies in that "dry tomb" landfilling approach for the protection of groundwater quality for as long as the buried wastes represent a threat, are coming to be well-recognized in the technical community. The disposal of "hazardous" and "non-hazardous" wastes in such landfills carries a significant, perpetual liability for clean-up of contaminated groundwaters and eventual "Superfund"-like activities for waste removal and proper management. Recycling and reuse can reduce long-term liability but waste residues associated with recycling, reuse, and treatment can, if not properly managed, create other areas of long-term liability.

The inability of US EPA-prescribed Subtitle C and D landfills to prevent groundwater pollution by landfill leachate for as long as the wastes are a threat should be of significant concern to all waste generators. Solid and hazardous waste generators should critically evaluate the potential near-term and long-term liabilities associated with any particular approach for waste management, resource recovery (including fuel blending, solvent recovery, and reuse), and management of waste residues. This paper reviews why landfills of the type being developed today do not eliminate long-term liability associated with wastes and issues of long-term liability associated with alternative methods of waste management.

INADEQUACIES OF CURRENT LANDFILL DESIGN, OPERATION, CLOSURE AND POST-CLOSURE MAINTENANCE

In the early 1980's the US EPA adopted the "dry tomb" landfilling approach for what it classifies as "hazardous" waste (Subtitle C). It officially adopted the "dry tomb" landfilling approach for municipal solid waste (MSW) management (Subtitle D) in October 1991. While the Agency has not yet promulgated

Summary of Key Problems with Subtitle D Landfills in Groundwater Quality Protection

- Wastes in "Dry Tomb" Landfills Threat to Groundwater Forever, i.e., for as Long as the Wastes Are in Landfill
- Plastic-Sheeting Liners Expected to Be Functional to Collect Leachate for Finite Period of Time
- Landfill Covers Will Not Prevent Moisture from Entering Landfill and Generating Leachate
- Groundwater Monitoring for Leachate-Pollution Not Reliable to Detect Incipient Pollution before Widespread Pollution Occurs
- Insufficient Post-Closure Funding Available to Reliably Address Ultimate Failure of Subtitle D Liners - 30-yr Period Unreliable

Conclusion: At Best, Current Minimum Subtitle D Landfills Only Postpone Groundwater Pollution

Conclusion
Groundwater Quality Protection by US EPA RCRA Subtitle D Landfill Approach

At Best, Will Only Postpone Pollution of Groundwater by Landfill Leachate
Will Not Likely Prevent Groundwater Pollution

Enables Today's Generation to Dispose of Garbage for Costs Less-Than-Real at Expense of Future Generations' Public Health, Groundwater Resources, and Financial Interests

Fundamental Issue

Define Objectives of Subtitle D Landfilling Requirements to:

Protect Groundwater Quality from MSW Leachate-Pollution for as Long as Wastes Are a Threat

or

Postpone Groundwater Pollution to Enable Current Waste Generators to Have Cheaper Garbage Disposal Today at Expense of Future Generations' Groundwater Resources and Future Financial Resources

Post-Closure Funding

Establish Dedicated Trust Fund Derived from Waste Disposal Fees

Sufficient Magnitude to Operate and Maintain Leak-Detectable Cover and to Exhume Wastes, if Necessary, at Any Time in Future

Closure of Classical Sanitary Landfills
◂ Current Approach ▸

- Place Low Permeability Cover (Compacted Soil) and/or FML on Landfill
- Install Groundwater Monitoring Wells
- 30 yrs Post-Closure Cover Maintenance & Groundwater Monitoring

  Maintenance - Kick Dirt in Cracks and Depressions

Not Reliable to Stop Further Groundwater Pollution

Will Slow Rate of Groundwater Pollution for a Period of Time

Closure of Classical Sanitary Landfills
◂ Important Needed Components ▸

- Install Leak-Detectable Cover
- Develop Dedicated Trust to Fund Maintenance of Cover and Pump & Treat
- Initiate Pump and Treat to Stop Groundwater Pollution Plume Spread & Treat to Clean Up Polluted Aquifer

Problems with Conventional Landfill Leachate Recycle "Bioreactor"

Basically Leachate Disposal

Likely to Lead to Increased Groundwater Pollution in Minimum Subtitle D Landfill

Single-Composite Liners Not Adequate Protection of Groundwater Resources during Leachate Recycle

Garbage Bags Interfere with Leachate Contact with Garbage

"Bioreactors" - Leachate Recycle in Minimum Subtitle D Landfill - Should Not Be Allowed

Alternative Landfilling Approach
◂ Wet Cell Fermentation Leaching ▸

Concept:

Provide *In Situ* Waste Treatment - Remove Hazardous & Deleterious Leachable Components - So Buried Residues Do Not Pose Threat to Groundwater Quality

Key Elements:

- Double-Composite-Lined Landfill
- Lower Liner Full-Landfill-Area Leak Detection System
- Shred Garbage
- When Landfill Cell Filled, Practice Leachate-Recycle
- Collect & Recover Landfill Gas
- When Landfill Gas Production Significantly Reduced, Add "Clean Water" to Leach Waste
- Continue Leaching until Wastes Are No Longer Threat to Produce Leachate That Threatens Groundwater Quality

Advantages of "Wet Cell" Fermentation and Leaching

- Landfill Leachate-Recycle Done during Time When Double-Composite Liner Likely to Function Effectively
- Thorough Leaching of Wastes Conducted under Controlled Conditions, Rather Than as Result of Failure to Properly Maintain Cover/Low-Permeability Layer

Need to Change RCRA to Allow Addition of Water to Landfill

Conclusions

- US EPA Subtitle D MSW Landfills Will Not Necessarily Protect Groundwater Quality for as Long as Wastes in "Dry Tomb" Landfill Will Be Threat
- Subtitle D Landfilling Cannot Be Reliably Monitored to Protect Groundwater Quality
- Wet-Cell Fermentation/Leaching Could Readily Be Implemented to Significantly Reduce Long-Term Liability That Occurs with Dry-Tomb Landfills

FORUM

ENVIRONMENTAL ETHICS: THE WHOLE TRUTH

Do engineers working on issues concerning the impacts of chemical constituents on public health or the environment have a professional obligation to tell the whole truth? The obvious answer is yes. Unfortunately, this is often not being done today.

The field of environmental quality management has become immersed in the adversarial (legal) system for "resolving disputes" among parties with different interests—a system significantly different from the traditional engineer/scientist (E/S) approach to addressing complex environmental issues. In the adversarial system, one side presents the strongest possible technical discussion on behalf of the client; it is left to the other side to bring out the weaknesses in the technical position. While such an approach is considered appropriate in the courtroom, the problem is that it is routinely followed by E/Ss in proceedings such as appearances before regulatory boards supporting or opposing proposed projects. Engineering and other technical reports commonly do not present a disinterested discussion of technical issues and information pertinent to the protection of public health and the environment.

When the responsible, competent E/S—who is charged to tell the truth complete with caveats, qualifiers, uncertainties and unanswered questions—presents the "whole" story to the client/employer, he or she is then frequently faced with a situation in which the client or employer wants only positive project-supportive information revealed and detracting information omitted. To be useful to the client/employer, the "expert" E/S must testify or otherwise make authoritative presentation of those selected facts and information in technical reports at hearings or other review-board proceedings.

Some professionals justify doing this on the grounds that they have to "play the game." The realities of maintaining a client, securing future work, and holding and advancing one's position in a firm, along with inadequate funding to conduct quality and necessary work compel some E/Ss to exaggerate, diminish or otherwise manipulate the whole truth—despite the fact that the codes of ethics of both ASCE and the National Society of Professional Engineers emphasize the importance of full disclosure on matters of public health and safety.

One way to help neutralize the effects of the adversarial system may be to incorporate a requirement with project applications for funding independent, disinterested technical review to be presented to the regulatory agency, decision makers and public. This approach is being followed in the siting of three large landfills to serve the Greater Toronto area.

It would provide considerable impetus for project consultants and advocates to be more forthcoming with reliable information on potentially adverse project impacts if they were faced with exposure of the technical unreliability (failure to tell the whole truth) of their positions in a full peer-review public arena. Such a review could also help address "not-in-my-backyard" concerns if individuals, communities and interest groups had a mechanism for independent review and reporting of technical information they felt they could trust. To fund this peer-review process, a percentage of the cost of any proposed project with potentially significant public-health or environmental-quality implications could be made available.

While environmental impact statements (or, in California, environmental impact reports) should by law provide the vehicle for full technical disclosure of potential problems associated with the project, such documents rarely provide reliable in-depth review of complex technical issues, especially as they relate to chemical constituents in the environment. Every project applicant should be required to conduct plausible worst-case–scenario evaluations for projects involving management of chemical constituents in the environment.

Such evaluations must include consideration of the nature, transport, fate and effects of chemical constituents under plausible worst-case conditions; the ability of the project's monitoring system to detect impending public-health and environmental-quality impairment under plausible worst-case conditions; the actions that would be taken in response to such detection; the magnitude of harm to public health and environmental quality that could result from inadequate response actions to plausible worst-case conditions; the magnitude and source of funding available for corrective action required under plausible worst-case conditions for as long as the wastes and/or chemicals represent a threat; and the adequacy of the public-health and environmental-protection regulatory standards or other requirements applicable to the project, as well as potential future changes in those standards. The plausible worst-case–scenario evaluation would be provided for peer review of the project.

Adoption of this approach would provide the public, the regulatory community and officers of the courts with a much better understanding of the potential consequences of undertaking a particular project or activity. It would also be a major step in reversing the tide of unethical practices that have become common among engineers and scientists in the environmental-quality-management field today.

[This Forum is condensed from a more comprehensive review of the topic, available from the authors at tel. 916/753-9630; fax 916/753-9956.]

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Modifications to Address Difficulties in Subtitle D Landfilling Approaches

Liner

- Double-Composite Liner
- Lower Composite Liner Is Leak Detection System for Upper Liner

Leak Detection

- Use the Presence of Leachate in Leak Detection System between Two Composite Liners as Indication of Liner Failure
- When System Detects Leachate Leakage That Could Pollute Groundwater if Lower Composite Liner Were Not Present, & It Cannot Be Stopped, Wastes in Landfill Must Be Removed from Landfill and Properly Managed

Landfill Cover

- Use Leak-Detectable Cover
- Operate and Maintain for as Long as Wastes Are a Threat

Post-Closure Funding

- Dedicated Trust Fund from Disposal Fees
- Fund Sufficiently Large and Reliable to Provide Post-Closure Maintenance and Waste Exhumation if Necessary
- A few ¢/person/day Added to Garbage Bill Should Generate Trust Fund Sufficient, if Properly Managed, to Meet Needs for Reliable Perpetual Post-Closure

Alternative Approach for Improving Groundwater Pollution-Prevention Using "Dry Tomb" Landfills

- Double-Composite-Lined Landfills - Lower Composite Liner Is Leak Detection System for Subtitle D Upper Composite Liner

  When Leachate Found in Leak Detection System between Two Composite Liners That Could Cause Groundwater Pollution if the Lower Composite Liner Were Not Present

  - Stop the Leakage
  - If Leakage Can Not Be Stopped, the Liner Considered Failed; the Wastes Must Be Removed if Groundwater Pollution to Be Achieved

- Use Leak-Detectable Cover for Landfill

  Operate and Maintain Forever

For Further Information on Problems with Landfilling Approaches and Alternative Approaches for Developing Landfills that Will Protect Groundwater, Public Health and the Environment for As Long As Wastes Represent a Threat Consult the Following:

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For these and additional, more recent, writings on these and related issues visit https://www.gfredlee.com