Superfund Site Remediation by On-Site RCRA Landfills: Inadequacies in Providing Groundwater Quality Protection

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ABSTRACT

One of the remediation technologies used at "Superfund" sites is an on-site landfill where hazardous wastes at the site are placed in a RCRA Subtitle C landfill or its equivalent. A critical review of the expected performance of RCRA Subtitle C (hazardous waste) landfills, however, shows that at best they will only postpone when groundwater pollution occurs and will not prevent groundwater pollution for as long as the wastes represent a threat. The wastes in most hazardous waste landfills will be a threat to groundwater quality forever. The landfill containment system (liners and covers) has a finite period of time during which it can be expected to function effectively to contain waste-derived constituents. Therefore, with few exceptions, ultimately both on-site and off-site Subtitle C landfills can be expected to eventually pollute groundwater with hazardous waste-derived leachate. In addition to the long-term problems that will be experienced at off-site landfills, on-site landfills will likely experience additional problems associated with difficulties of obtaining reliable post-closure care. This paper discusses the problems with Subtitle C landfill design, closure and post-closure care and provides recommendations on how on-site and off-site hazardous waste Subtitle C landfills should be developed to provide for true public health, groundwater resource and environmental protection for as long as the wastes placed in the landfill will be a threat.

INTRODUCTION

Increasingly, on-site RCRA Subtitle C "hazardous waste" landfills are being used as remediation approaches for federal and state "Superfund" sites. This approach is being advocated based primarily on the cost of alternative treatment technology, such as incineration of organics, solidification - fixation of inorganics - organics, etc., as well as off-site landfilling. It is often asserted by the PRPs and the regulatory agencies that construction of such a landfill at a "Superfund" site represents a technically valid, cost-effective approach for managing hazardous chemicals that complies with CERCLA or state "Superfund" remediation requirements. This paper reviews the characteristics of RCRA Subtitle C hazardous waste landfills with respect to their ability to provide permanent, highly reliable hazardous waste management for as long as hazardous waste and/or hazardous waste residues placed in the landfill represent a threat to public health, groundwater resources, the environment and the interests of those who own or use properties within the sphere of influence of the landfill.

While the focus of this paper is Subtitle C landfills, the same issues apply to RCRA Subtitle D (non-hazardous waste) landfills. The significant deficiencies in RCRA Subtitle

D landfills in preventing groundwater pollution by waste-derived constituents for as long as the wastes in the landfill represent a threat has been recently reviewed by Lee and Jones-Lee (1996).

CHARACTERISTICS OF RCRA SUBTITLE C LANDFILLS

RCRA Subtitle C "hazardous waste" landfills are based on the "dry tomb" landfilling approach in which hazardous wastes and/or hazardous waste residues that have been treated to some degree before deposition in the landfill are enclosed in plastic sheeting and compacted soil - clay layers in an effort to develop a "tomb." In principle, this approach is supposed to isolate the wastes from contact with moisture that will generate leachate that can pollute groundwaters for as long as the wastes in the landfill are a threat. A low permeability, but not necessarily impermeable, cover is placed over the landfilled waste. The sides and bottom of the landfill are lined with a double composite liner consisting of compacted soil - clay layer with a permeability no greater than 1×10^{-7} cm/sec at the time of construction overlain by an HDPE plastic sheeting (flexible membrane liner - FML). Between the two composite liners is a leak detection system in which leachate that passes through the upper composite liner would, in principle, be transported to a sump where it could be detected and removed.

The "dry tomb" landfilling approach assumes that any moisture that penetrates through the cover that generates leachate would be collected in a leachate collection removal system which is constructed above the upper composite liner. This system typically consists of a granular material of high permeability that will allow leachate to flow on top of the upper composite liner FML to a sump where it can be collected and removed generally by pumping. In principle, any leachate that penetrates through the upper composite liner could be detected and collected in the leachate detection system between the two composite liners.

Groundwater monitoring is used to "detect" if leachate and/or landfill gas penetrates through the lower composite liner into the aquifer system underlying and near the landfill. Vertical monitoring wells are placed at the point of compliance for groundwater monitoring typically within 150 meters of the down-groundwater gradient edge of the landfill. These vertical monitoring wells are often spaced hundreds to a thousand or more feet apart along the vertical plane representing the point of compliance.

Funding of post-closure maintenance and monitoring of the landfill is required for a minimum of 30 years after closure (cessation of waste deposition). While there are provisions for increasing the post-closure maintenance and monitoring period, there are no funds set aside for this purpose under current Subtitle C landfilling requirements. Nor are any funds available to address failure scenarios, such as clean up of polluted groundwaters, waste exhumation, etc.

PROBLEMS WITH CURRENT SUBTITLE C LANDFILLING APPROACHES

This landfilling approach evolved from environmental activists lobbying Congress to require that the revision of RCRA include a specific landfill design equivalent to the current Subtitle C design (double composite liner system described above). Congress dictated to the US EPA how the agency should design, regulate operations, close and provide post-closure care for hazardous waste landfills. This design was not based on a reliable assessment of the ability of the liner, cover and monitoring system to protect groundwater from pollution by waste-derived constituents for as long as the wastes are a threat. RCRA does not require that a Subtitle C or D landfill protect groundwaters from impaired use for as long as the wastes represent a threat. RCRA specifies a minimum design standard for landfills. It is widely recognized and, in fact, obvious at the time when the revised RCRA was adopted that, when the properties of the liner materials (compacted soil and plastic sheeting) that are used today are evaluated that Subtitle C and D landfills only postpone when groundwater pollution will occur. However, some states, such as California, landfilling regulations explicitly require that the landfill containment system (liner and cover) contain the wastes and/or prevent groundwater use impairment for as long as the wastes are a threat. While these requirements exist, the state regulatory agencies are not yet enforcing them.

It is recognized that these wastes and treated waste residues will be a threat, effectively, forever. Obviously the liners under the landfill will not be effective in preventing leachate from passing through them for as long as the wastes are a threat.

Since the cover for Subtitle C landfills is not impermeable, moisture will enter the wastes and generate leachate. Since the flexible membrane liner which is the key element of the composite liner in preventing leachate passage through the liner will deteriorate and since this liner cannot be inspected and repaired, eventually all Subtitle C landfills will "pollute" the aquifer underlying the unsaturated (vadose) zone. Those landfills sited where there is a hydraulic connection between the vadose zone underlying the landfill and waters that at any time in the infinite future could be used for domestic water supply eventually will be polluted by landfill leachate.

While it is sometimes asserted that the unsaturated and saturated zones under the landfill will attenuate constituents in the wastes by sorption, precipitation or chemical or biochemical transformations and, thereby, prevent groundwater pollution, most hazardous wastes contain constituents which are not removed by attenuation other than dilution which can render a groundwater unusable for domestic water supply purposes.

The key to making a "dry tomb" landfill function as designed for as long as the wastes represent a threat is the integrity of the flexible membrane liner in the landfill cover. If the cover of a landfill can, in fact, be developed that would prevent moisture from entering the landfill for as long as the wastes are a threat, then the dry tomb landfilling approach could be made to prevent groundwater pollution. While Subtitle C landfill covers typically include a composite liner system, the compacted clay layers in such a cover will experience significant desiccation and differential settling cracking and, thereby, cause them to be ineffective in preventing moisture from entering the landfill

through the clay layer. The problems with compacted clay layers serving as an effective barrier to moisture entering landfills have been recently discussed by Daniel (1995).

The low permeability layer (FML) of the landfill cover will deteriorate over time allowing increasing amounts of moisture to enter the landfill generating leachate. In a typical Subtitle C or D landfill cover, the low permeability layer is buried below one or more feet of topsoil and, for many landfills, a drainage layer. As a result, visual inspection of the cover - typically the approach used to determine when the cover needs maintenance - will not detect significant cracks in the cover low permeability layer that will allow greater-than-designed moisture entrance to the landfill. The result is that landfill covers will permit much greater moisture to enter the landfill than predicted based on typical estimates using the HELP model or some other similar approach. Such estimates are only applicable to the time at which the landfill's cover is constructed provided that high-quality construction is, in fact, achieved. The users of the HELP model typically fail to consider the deterioration in the properties of the cover with time with the result that the HELP model-based calculations of leachate generation rates are often low compared to the actual rates of leachate generation.

Frequently, landfill applicants and their consultants claim that, since the annual moisture gradient for a landfill located in arid areas of the US is to the atmosphere, no leachate is generated in the landfill. It is inappropriate to use net annual moisture flux direction to estimate the potential for leachate generation. Short periods of high moisture input, such as after a moderate to intense precipitation event, allow sufficient moisture to enter the landfill generating leachate that can lead to groundwater pollution.

Another mistake that is commonly made is to assume that the moisture-holding capacity (field capacity) of the wastes must be exceeded before the wastes will generate leachate that can pollute groundwater. Such an approach ignores unsaturated transport of leachate-derived constituents in the waste and in the underlying aquifer. While landfills in desert areas produce less leachate than landfills in wetter areas, the arid area landfills generate sufficient leachate to pollute groundwaters. Small amounts of moisture can generate leachate that, because of the strength of leachate, pollutes substantial amounts of groundwater rendering them unusable for domestic water supply purposes.

The moisture that enters the landfill generates leachate which when the landfill liner system is new, and high-quality construction is achieved and initial operation of the landfill does not result in holes being made in the liner, is largely collected in the leachate collection and removal system. However, over time the plastic sheeting flexible membrane liner will deteriorate and eventually become ineffective in collecting - transporting leachate to the sump where it can be removed. The compacted soil layer underlying the flexible membrane liner can transport significant amounts of leachate through it at design permeability. Further, there are a wide variety of factors, such as desiccation cracking, that cause the compacted clay layer liner to have poor reliability in preventing leachate from passing through it.

The US EPA (1988) as part of developing Subtitle D regulations, summarized the expected long-term performance of composite liners,

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

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"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."

Lee and Jones-Lee (1993a) have discussed the ability of plastic flexible membrane liners to prevent leachate from passing through them for as long as the wastes in a landfill represent a threat. While no one can reliably predict how long the flexible membrane liners in a Subtitle C landfill will be effective in preventing leachate from passing through them, ultimately, the leachate containment properties of these liners will deteriorate while the wastes still remain a threat.

Further, the groundwater monitoring approach allowed under Subtitle C for detecting liner leakage is a flawed technological approach toward reliably monitoring groundwater pollution by landfill leachate. As discussed by Cherry (1990) and Lee and Jones-Lee (1994a), the vertical monitoring wells used have zones of capture of about one foot around each well. When they are spaced hundreds to a thousand or more feet apart, there is a high probability that the finger plumes of leachate produced by the initial leakage of leachate through the liner system will not be intercepted by the vertical monitoring wells with the result that large amounts of groundwater downgradient from the point of compliance can be polluted with leachate-derived constituents before the vertical monitoring wells detect this pollution.

The US EPA Subtitle C "dry tomb" landfilling approach is obviously a flawed technology that, at best, only postpones when groundwater pollution occurs by landfill-derived leachate.

There is need to revise RCRA and the US EPA Subtitle C regulations to develop landfilling approaches for hazardous wastes that will, in fact, protect groundwater resources from pollution by landfill leachate for as long as the wastes in the landfill represent a threat.

THREAT OF HAZARDOUS WASTE LEACHATES TO PUBLIC HEALTH AND GROUNDWATER RESOURCES

It is assumed in this discussion of landfilling of hazardous wastes in a Subtitle C landfill that the hazardous wastes have been treated at least to conventional TCLP standards so that there are no leachate components in the waste that exceed, under the conditions of the TCLP test, 100 times drinking water standards. Not all hazardous wastes placed in

Subtitle C landfills are "treated" to TCLP standards. The US EPA and some states allow the deposition of some types of hazardous wastes in Subtitle C landfills without treatment. While treatment to meet TCLP standards significantly reduces the hazard associated with many hazardous wastes, it does not eliminate it for the regulated chemicals and does not address the unregulated chemicals which may be the bulk of the hazardous/deleterious substances in hazardous waste.

A group of chemicals of concern associated with landfills, whether classified as hazardous or domestic waste, is the unregulated non-conventional pollutants. Most of the organic carbon present in hazardous waste leachate is of unknown characteristics. Only about 200 out of about 60,000 chemicals that are used in everyday commerce in the US are regulated today. The treatment of hazardous waste to meet TCLP type standards for leachable components does not eliminate this problem. There is, therefore, a vast arena of potentially hazardous chemicals as well as chemicals that can be deleterious to domestic water supply water quality in hazardous waste leachate that, when present in groundwaters, can render these groundwaters unusable for domestic and many other purposes.

It is because of the non-conventional pollutants that it should never be assumed that if a water meets drinking water standards (maximum contaminant levels) that this water is safe to consume if it is known to contain hazardous waste leachate. There could readily be unregulated chemicals present in the leachate which are highly hazardous to public health even though the groundwater polluted with the leachate meets all drinking water standards.

Another group of constituents in hazardous waste leachate, that is not now regulated under RCRA and CERCLA, that is of concern because they adversely impact groundwater quality are the conventional pollutants such as total salts, total organics which can impact the aesthetic quality through taste, odors, color, etc., iron, manganese, hardness, chloride, hydrogen sulfide, etc. These constituents are of concern to domestic water supply water quality. Increases in concentrations not only adversely impact public health, but also the palatability - usability of the water. Further, a number of these constituents are of economic importance to the public through increased corrosion, scale formation, etc. of distribution systems, plumbing fixtures and various appliances.

While RCRA and CERCLA focus regulatory activities on a narrowly defined group of hazardous chemicals, there is a much greater arena of chemicals in hazardous wastes that need to be regulated in any on-site, as well as off-site landfilling operation. Some states, such as California, require that both hazardous and so-called non-hazardous waste landfills prevent the use impairment of groundwaters by waste-derived constituents for as long as the wastes represent a threat. This is the approach that should be adopted nationally. The current RCRA and US EPA approach of only addressing a few hazardous chemicals in landfill leachate and then assuming that if all of the regulated chemical concentrations are below MCLs, that the presence of hazardous waste leachate in a water is of no importance, is obviously a flawed approach that should be changed to properly

protect public health and groundwater quality from pollution by landfill hazardous waste leachate.

In summary, today's landfills' hazardous waste leachate represents a significant threat to groundwater quality that can be highly hazardous to public health and/or significantly detrimental to groundwater quality. It is, therefore, essential that the landfilling of hazardous wastes be conducted in such a way as to prevent leachate from leaving the landfill at those locations where it could reach saturated groundwaters that, at some time in the future, could be used for domestic purposes.

Overall, Subtitle C landfills receive wastes that represent highly significant threats to public health, groundwater resources and the environment. The current landfilling approach only postpones when groundwater pollution occurs for those landfills that are sited in areas in which the landfill is hydraulically connected to groundwaters that can be used for domestic water supply purposes at any time in the future.

There is an obvious need for alternative landfilling approaches if public health and groundwater are to be protected from pollution by landfill leachate for as long as the wastes in the landfill represent a threat, i.e. forever.

LANDFILL DESIGN, OPERATION, CLOSURE AND POST-CLOSURE CARE PERFORMANCE STANDARDS

Even though it has been well-known since the 1950s that landfills represent significant threats to groundwater quality, it was not until about 1980 that regulatory approaches were adopted and implemented which were at least initially designed to prevent groundwater pollution by constituents in solid waste. Unfortunately, the US EPA - environmental activists made a serious error in developing the "dry tomb" landfilling approach. This appears to have evolved out of the significant mistake that was made in assuming that landfill wastes only represented a threat for 30 years after closure.

As discussed by Lee and Jones-Lee (1993b, 1994b), the mandated 30-year post-closure care period appears to have evolved out of the misconception that the normal sanitary landfill's 30 to 50 year landfill gas production period was the only issue of concern. While landfill gas is an important potentially hazardous emission from landfills because of its VOC content (Prosser and Janechek 1995), often of even greater importance is the potential to pollute groundwater by landfill leachate. Landfill gas production and landfill leachate production are not directly linked.

The leaching of chemical constituents from hazardous waste and municipal solid waste can take place in a classical sanitary landfill for thousands of years and still produce a leachate that is significantly adverse to groundwater quality. Belevi and Baccini (1989) have developed a model that predicts that conventional sanitary landfills in Switzerland will be threats to groundwater quality through the leaching of lead that is normally present in municipal solid waste for over 2,000 years.

In the "dry tomb" landfill, the period of time will be extended to the extent that the "dry tomb" character of the landfill is, in fact, achieved and maintained. With little or no moisture in the landfill, the wastes will remain unfermented and unleached. However, as soon as those responsible for maintenance of the "dry tomb" provide inadequate maintenance and moisture enters the landfill, then the process of environmental pollution associated with landfill gas and leachate emissions from the landfill will proceed. If this process occurs early in the post-closure period while the liner system is still functioning relatively effectively, the leachate that is generated in the landfill will, at least to some extent, be collected in the leachate collection and removal system. In time, however, the efficacy of the leachate collection and removal system to remove leachate will deteriorate due to the deterioration of the flexible membrane liners and in effect become non-functional in collecting sufficient leachate to prevent groundwater pollution.

While there is insufficient information on the long-term characteristics and use history to reliably predict the period of time when the FML liner will fail to be effective in collecting and removing leachate, it is likely to be on the order of a few decades and may be on the order of 100 or so years. There is no question, however, that ultimately the wastes will be a significant threat to groundwater pollution far longer than the "dry tomb" liner systems, including double-composite liners, that will prevent leachate generated in the landfill from entering groundwaters near the landfill. The inorganic salts, heavy metals and many organics will be a threat to groundwater quality effectively forever. Even if the liner system is effective in preventing leachate from passing through it for 100 or so years, still at the end of this period, future generations will face pollution of their groundwater resources by leachate from today's Subtitle C landfills. Therefore, rather than planning the post-closure maintenance period for 30 years, as is currently practiced for Subtitle C landfills, the post-closure care maintenance period should assume that leachate can be generated in the landfill for as long as the landfill will exist which in most cases will be forever.

The state of California Water Resources Control Board adopted Title 23 Chapter 15 regulations in 1984 which set forth the overall performance standard for landfills developed in that state to, as a minimum, protect groundwater quality from impaired use from all constituents for as long as the wastes in the landfill represent a threat. This is the only sensible regulatory approach for establishing landfill containment system design performance standards whether hazardous or non-hazardous.

It is important not to confuse minimum landfill containment system component design standards set forth in Subtitle C and state regulations with the overall landfill containment system performance standard. The purpose of the containment system (liners, leachate collection and removal and cover) is obviously to prevent pollution of groundwaters by landfill leachate. Regulatory agencies at the federal and state level specify minimum landfill individual component design standards that can be used in some situations. Today, however, landfill applicants, their consultants and some regulatory agencies are allowing Subtitle C landfills to be constructed which only utilize individual containment system component minimum design standards. It is obvious, however in review of such landfills, that using the minimum design standard for a component of the containment

system set forth in the regulations will not achieve the overall landfill containment system performance standard of protecting groundwaters from pollution from landfill leachate for as long as the wastes in the landfill represent a threat. It is important that in review of the liners, covers, groundwater monitoring systems, etc., for a landfill that an evaluation be made of whether the containment system components will be protective of public health and the environment for as long as the wastes represent a threat.

MODIFICATION OF SUBTITLE C LANDFILLS TO PROVIDE FOR TRUE PUBLIC HEALTH, GROUNDWATER QUALITY AND ENVIRONMENTAL PROTECTION

The basic question that needs to be addressed is can "dry tomb" landfills be modified so that they will, in fact, provide for true public health, groundwater resource and environmental protection for as long as the wastes in the landfill represent a threat? As discussed below, technology is being developed today that will enable "dry tomb" landfills to be a technically-valid approach for managing treated hazardous waste residues. Unfortunately, the implementation of this technology is limited since as long as the regulatory agencies at the local, state and federal level allow landfilling at less-than-real cost, responsible parties will continue to opt for the initial cheaper-than-real cost disposal of waste in order to remain competitive.

Landfill Liner Design. All "dry tomb" type landfills for hazardous wastes and treated residues should be designed with a minimum of double-composite liners with a leak detection system between the two composite liners. This leak detection system should be a high permeability layer of sand or other medium that is not subject to significant clogging by leachate-induced biological growths. It should be understood that the lower composite liner is not a containment liner but is part of the upper composite liner leak detection system, i.e. a full landfill area pan lysimeter.

The key to protection of groundwater quality in a double-composite lined landfill where the lower composite liner's function is primarily that of a leak detection system for the upper composite liner is the ability to take appropriate action when leachate is found in the leak detection system between the two composite liners. When leachate is found there that could result in groundwater pollution if the second composite liner were not present, it has to be assumed that the upper composite liner has failed. At that time, if the landfill owner/operator cannot stop the leachate from entering the leak detection system below the upper composite liner, then there is no alternative but to remove the wastes from the landfill since it is only a matter of time until there will be failure of the second composite liner and pollution of any groundwaters associated with the hydrogeologic system in which the landfill is located.

Landfill Covers. The key to developing a "dry tomb" type landfill that will protect groundwater quality for as long as the wastes represent a threat from impairment by landfill leachate is the ability to provide an impermeable cover on the landfill. Current Subtitle C landfill covers contain a low permeability layer. However, this layer will not prevent moisture from entering the landfill. Substantial moisture can enter the landfill

through the cover due to a variety of mechanisms through cracks, holes, rips and tears in the plastic sheeting of the cover as well as differential settling-caused cracks and desiccation-caused cracks in any compacted clay layers that are present in the cover.

Until about two years ago, it was concluded that inevitably all "dry tomb" type landfills will fail and if there is an interest in protecting groundwater resources hydraulically connected to the landfill from pollution by landfill leachate, it would be necessary to exhume the wastes from the landfill when leachate passes through the upper composite liner. In the past couple of years, however, two commercially available leak testable landfill cover systems have been developed which have changed this situation. The Robertson system (Robertson Barrier System Corp., Vancouver, BC, CANADA) utilizing a double FML sandwiched on a geonet in which a vacuum is applied to the sandwiched FMLs, can detect when there are holes in one of the FMLs, and therefore indicate the need for repair. Also, GSE Lining Technologies Inc. (formerly Gundle) of Houston, Texas, USA, has imported an electrical leak detection system for FMLs from Europe which can be used to detect holes in the FML in a landfill cover and thereby indicate the need for repairs in a specific area of the cover.

Installing a leak-detectable cover and its *ad infinitum* operation and maintenance can create a true "dry tomb" that will prevent leachate formation; however, these covers must be operated and maintained forever. Additional information on landfill post-closure issues and the use of leak detectable covers is provided by Lee and Jones-Lee (1995).

FUNDING "DRY TOMB" LANDFILL POST-CLOSURE CARE ACTIVITIES

One of the most significant deficiencies of Subtitle C regulations is the failure of the US EPA and the states to properly assure funding of Subtitle C landfill post-closure care activities for as long as the wastes in the landfill will be a threat. As discussed above, environmental groups, Congress and the US EPA made a significant error in implementing Subtitle C landfilling requirements in only mandating 30 years of assured post-closure care.

The GAO (1990) reviewed the hazardous waste landfill post-closure care funding situation and concluded that funding is not necessarily available to meet expected contingencies including eventual clean-up of contaminated groundwaters associated with the landfill when the liner systems fail to collect the leachate generated within the landfill to a sufficient extent to prevent significant groundwater pollution.

While it could be argued that the additional funding that will be needed in year 31 and beyond after closure will become available, the likelihood of this being the case is small. This is especially true for on-site landfills at "Superfund" sites. All one has to do to understand this situation is to examine how governmental agencies at the federal, state and local level are now closing former dumps and sanitary landfills. There are many tens of thousands of dumps and landfills across the US that are polluting groundwaters that have not been addressed with respect to stopping this pollution primarily because the local communities responsible for the landfills claim that they do not have the funds

available to require that the landfill be properly closed and that the polluted groundwaters be cleaned up to the maximum extent practicable. The same situation will likely occur at most Subtitle C landfills where future generations will face the same problems of trying to find funds to stop further pollution of the groundwater resources in the vicinity of the landfill by leachate and to clean up the pollution that has already occurred.

Hickman (1995), Executive Director of the Solid Waste Association of North America, in an article entitled, "Ticking Time Bombs?" discusses the inadequacy of the current approaches that are frequently used for providing assured long-term funding for post-closure care activities for today's landfills. He states,

"I think that what we have done, in those instances where these landfills do not have a dedicated trust fund, is to build another generation of ticking time bombs that will go off after we have gone. When that occurs, sometime in the future another generation of Americans will be left with a bill to pay that we should be paying now."

Hickman (1992) discusses the problems with many of the financial instruments used today to "assure" that funds will be available to meet post-closure care needs and contingencies for today's "dry tomb" landfills. He points out that today, the only reliable financial instrument to assure post-closure care needs is a dedicated trust.

As part of developing a hazardous waste landfill for on-site management of wastes, the responsible parties should be required to set up a dedicated trust fund of sufficient magnitude to meet all plausible worst-case scenario contingencies that could develop at the landfill at any time in the future.

ALTERNATIVE WASTE DISPOSAL PRACTICES

While the US EPA adopted the "dry tomb" landfilling approach for hazardous and municipal solid wastes, other countries have examined this approach and determined that it is a technically flawed approach to provide true groundwater quality and public health protection from waste components. Increasing recognition is being given in the US and in other countries to the need to treat hazardous wastes, either before burial or at the time of burial within the landfill (*in situ* treatment), in order to eliminate the pollution of groundwaters by landfill leachate. While RCRA does require some treatment of some types of waste before landfilling and restricts the landfilling of certain types of waste, this treatment as typically practiced today is not adequate to address the long term problems associated with the hazardous and deleterious characteristics of the leachate that is produced in a Subtitle C landfill. This can be readily understood by examining the characteristics of the leachate that is produced in Subtitle C landfills. There are few individuals who would willingly accept such leachate in their drinking water even if none of the regulated constituents exceed an MCL.

In the US, increasing attention is being given to the use of municipal landfill leachate recycle where leachate developed in the landfill is introduced back into the landfill. Such practices increase the hydraulic loading on the landfill and thereby can stimulate the

conversion of fermentable organics into landfill gas. While this approach is said to "stabilize" a landfill, the word "stabilize" is often misinterpreted since leachate recycle as it is being practiced, does not address the most important problems associated with municipal solid waste landfills, namely the pollution of groundwaters by leachate.

Lee and Jones-Lee (1993c) have recommended that a true "wet-cell" approach be used in all landfills where a double composite-lined landfill is constructed in which the lower composite liner is a leak detection system for the upper liner in order to ensure that no pollution of groundwaters occurs because of the increased hydraulic loading on the landfill associated with leachate recycle. The Lee and Jones-Lee "wet-cell" fermentation and leaching approach involves the recycle of leachate for a period of time until all fermentable organics are converted to landfill gas. After that time, a clean water washing of the waste takes place in order to remove the leachable components from the waste. This approach could be applied to hazardous waste landfills to remove those leachable components in the treated wastes that represent long term threats to groundwater quality. This leaching - washing of the wastes would be under controlled conditions where the liners are expected to be effective in collecting leachate. Any failure of the upper composite liner could be readily detected and the washing of the wastes terminated upon detecting leachate in the leak detection system between the two composite liners.

CONCLUSION AND RECOMMENDATIONS

Today's US EPA Subtitle C hazardous waste landfills utilize a flawed technological approach for the development of a landfill containment system that at best only postpones when groundwater pollution occurs. There is need to change RCRA and/or state regulations to:

- require that a double-composite liner be used for Subtitle C landfills where the lower composite liner is a leak detection system for the upper liner.
- require that when the landfill owner/operator cannot stop leachate from occurring in the leak detection system between the two composite liners that the wastes in the landfill must be removed from the landfill.
- require the closure of Subtitle C landfills with leak detectable covers that are operated and maintained for as long as the landfill exists.
- eliminate the minimum 30 year post-closure care and maintenance period and require that post-closure care be provided for as long as the wastes in the landfill represent a threat which is understood in a "dry tomb" type landfill to be forever.
- require that an adequate dedicated trust fund be developed at the time of developing the landfill to ensure that funds will, in fact, be available when needed for perpetual monitoring, maintenance, care and to meet any plausible worst-case contingencies that could occur at a landfill including waste exhumation and clean up of polluted groundwaters.

Because of the very high perpetual, *ad infinitum* costs associated with "dry tomb" landfilling that provide for true protection of public health, groundwater resources and the environment, it is recommended that the "dry tomb" landfilling approach be

abandoned as soon as possible in favor of a waste-treatment approach that produces residues that do not represent long-term threats to groundwater quality, public health and the environment.

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