Risk assessment as an engineering tool in landfills

A. Mavropoulos¹, D. Kaliampakos²

¹EPEM SA, Athens, Greece.
²National Technical University of Athens, Greece.

Abstract

Risk assessment has been widely used as a tool for the development of waste management facilities. At the strategic level, risk assessment is used to inform decision makers about the planning process. In terms of a specific site, environmental risk assessment is used to identify risk management options. As an engineering tool, risk assessment is used to optimize the mitigation measures required to prevent, control or minimize the risks to the environment from the site. The use of risk assessment techniques in landfill design and in uncontrolled dumps remediation / rehabilitation has provided remarkable results in terms of cost savings and environmental protection. This paper aims to present risk assessment applications in landfilling and thus to outline the key role of risk based engineering. Landfill risk analysis procedures, as well as applications in failure assessment and waste acceptance criteria are presented.

1 Introduction

Risk assessment has usually been applied to two major areas:
- Adverse health and environmental effects of exposure to hazardous chemicals
- Failure of complex technological systems

The use of risk assessment in waste management facilities and especially in landfills has been increased since it was understood that landfills cover both of the previous areas. Landfills are transformed to complex technological systems, since the use of liners, leachate and biogas collection and treatment equipment has been generalised. At the same time all the landfills, especially hazardous waste landfills, can result in serious environmental and health effects due to both construction and operational problems.
The more modern landfill experiences are cumulated, the more risk assessment procedures are involved to almost all the levels of a landfill life cycle. Risk analysis can assist development and/or change of waste management regulations. In USA and UK risk assessment procedures are strongly related to waste management licensing [1,2]. Regarding site allocation a preliminary risk assessment provides decision-makers with useful data that allows to select where the procedure should continue or stop.

The risk involved with contaminant releases from landfills or uncontrolled dumps is another scientific area that risk assessment has been widely used. Risk analysis can support decision-making on establishing priorities in remediation activities as well as selecting remediation alternatives for individual contaminated site [3]. For modern landfills, such as landfills that are in accordance with high environmental performance standards, risk assessment procedure need to encompass considerations of failure of landfill technology as well [4].

In landfill design the understanding of the physical-chemical and mechanical characteristics of the materials used is of major importance. Principles of risk assessment are applied not only to the overall design but also right down to the detail of individual materials and their methods of installation [5].

In developing countries, simplified risk-based methodologies have been developed in order to provide the necessary Minimum Requirements of a landfill, in terms of conceptual design [6,7].

Waste acceptance criteria are also developed with the use of risk-based procedures, for different kind of disposal facilities [8,9].

The aim of this paper is to provide a clear idea regarding the key role of risk assessment procedures in landfill design, construction and operation. In order to achieve this the following issues will be discussed:

- The framework for risk-based engineering in landfills.
- The use of risk-based approaches in order to evaluate alternative designs.
- The use of risk-based techniques for the evaluation of operational issues.
- The use of risk-based approaches for the determination of waste acceptance criteria.

2 The framework for risk-based engineering in landfills

Risk analysis in waste management facilities usually combines Engineering Risk Assessment and Ecological Risk Assessment. Both terms will be covered under the term “Environmental Risk Assessment” within the context of this paper. Environmental risk assessment and management typically involves answers being sought to the following questions:

- What environmental hazards are present and what are their properties?
- How might the receptors become exposed to the hazards and what is the probability and scale of exposure?
Given exposure occurs at the above probability and magnitude, what is the probability and scale of harm?

How significant is the risk and what are the uncertainties?

What needs to be done to prevent, control or minimize the risks?

Within this approach the source-pathway-receptor concept holds a key position. The 'source' for waste management facilities is defined by the hazardous properties of the waste types and operations to which they will be subjected on the proposed site. The environmental 'receptors' (or targets') are those entities which are liable to be adversely affected by the identified hazards transferred from the defined 'source' into the environment by the identified 'pathways'. 'Pathway' is the mechanism by which the receptor and source can come into contact.

Modern landfills are characterized by the multi-barrier concept, meaning that for every possible emission to the environment several barriers are developed. The containment engineering for a landfill is essentially the mitigation for the site’s risk to the environment. Thus containment engineering serves as a pollution prevention system: the 'source' of pollutants (leachate, gases) is blocked by leachate and biogas collection and treatment equipment and the link with a possible 'pathway' (and consequently with a 'receptor') is impossible.

Fundamental to environmental risk assessment is the conceptual model stage, which enables a clear picture to be established of the site and its environment, based upon the nature of the site and its environmental situation [10]. Figure 1 presents a typical conceptual model of landfill sources, pathways and receptors [11].

Figure 1: Conceptual model for source – pathways – receptors in a landfill [11]
Consequently the framework for risk analysis in landfills include both:

- The environmental and health risks once contaminants have been released.
- The risks of failure of the contaminant containment system.

A failure of the containment system transforms the landfill into a ‘source’ and allows the link with ‘pathways’ and ‘receptors’. In order to characterize and estimate the risk one has to characterize and combine the characterizations of all the three elements of the chain ‘source’ – ‘pathway’ – ‘receptor’.

2.1 Objectives

During landfill design, construction and operation there are several cases where a risk assessment procedure is, probably, the only way to find out answers in specific questions. Some of the most common questions are:

- What is the appropriate liner for the landfill?
- What is the appropriate capping?
- How complex and expensive should the leachate treatment facility be?

All these questions can be answered using risk analysis. In order to be effective risk assessment in landfills should serve the following objectives [5]:

- To prevent uncontrolled releases of leachate and gases
- To ensure that works and materials are fit for the purpose specified and their lifespan is suitable for the required environmental protection.
- To ensure that the engineering design will provide a stable environment capable of performing to a prescribed specification throughout the design life of the site.
- To ensure that the works are quality assured in high standards

2.2 Handling the Uncertainties

The main limitation in the use of risk analysis in landfills becomes from non-availability of reliable data for all the elements of the risk characterization chain. Waste input is not uniform in terms of composition and its temporal and spatial distribution within the landfill can not be easily simulated.

The materials used for the construction of containment systems can be divided in two categories. Materials like clay and sand are well-known in civil engineering works and their behavior may be predicted in some cases. Other relatively new materials like geomembranes or other polymeric foils are not so known and their behavior, especially the long – term one, can not predicted. Also it is not known in a sufficient way what is the long – term behavior of composite systems and the interactions between different kinds of materials, which is the most common case in modern landfills.

Things become more difficult due to lack of long – term experience with modern landfill systems, although their lifespan as active bioreactors is much more than 100 years. Laboratory tests can not provide sufficient data due to their short duration and to the difficulties to simulate the physical, chemical, mechanical and biological conditions of a landfill.
It is surely very difficult and sometimes impossible to find systematic data regarding success or failure of the main landfill containment systems like liners, leachate collection systems, drainage layers, biogas collection network etc. Thus uncertainties are an internal, structural problem in risk assessment on landfills. An efficient way to overlap the problem of uncertainties in landfills is the use of expert panels [12].

3 Evaluation of alternative designs

One of the most common and successful applications of risk assessment in landfills is the evaluation of alternative designs. A typical problem when a landfill is designed is to select the most appropriate liner system. The liner system must fulfill the following criteria:

- It must meet the legislation specifications.
- It must be as cheap as possible.
- It must satisfy the environmental protection standards of the specific site.

Normally there are much more than one liner that seems to satisfy the two first preconditions. The only way to assess if a liner meets the local environmental protection standards (in short and long term) is a risk assessment procedure. Typically such a procedure starts with the listing of all the possible hazards that could transform the containment system into a ‘source’. Table 1 provides such hazards for design, construction, operation and post-closure.

Table 1. Hazards listing for a liner failure.

<table>
<thead>
<tr>
<th>DESIGN HAZARDS</th>
<th>CONSTRUCTION HAZARDS</th>
<th>OPERATION HAZARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrong base slopes</td>
<td>Inadequate sub-base preparation</td>
<td>Damages to liner due to operational mismanagement</td>
</tr>
<tr>
<td>Wrong membrane thickness</td>
<td>Poor quality control of materials used</td>
<td>Failure of leachate collection system due to bad operational practices</td>
</tr>
<tr>
<td>Wrong leachate collection system</td>
<td>Penetration of liner containment system</td>
<td>Excessive rainfall</td>
</tr>
<tr>
<td>Wrong leachate generation estimation</td>
<td>Absence of QA/QC procedures</td>
<td></td>
</tr>
</tbody>
</table>

Then for each design, the following steps are implemented:

- Fault trees are created to present the routes by which these events may occur.
Quantification of these fault trees produces the likelihood, or probability, of such events to occur.

The potential environmental impacts of the consequences of these events are determined. A typical example in the case of liners is the determination of the resultant leak rate. This rate can be used as input to a groundwater model and thus the pollution plume can be calculated and compared with the environmental standards.

In case all the alternatives meet the environmental standards, then an engineering feasibility study is necessary. One significant benefit of risk analysis is that it provides a way to link capital and operational costs to real environmental results.

Using the results of risk analysis a relative cost-benefit analysis can be implemented. Table 2 show results of such an analysis [13] combining the results of risk assessment with capital costs for four alternative liners.

<table>
<thead>
<tr>
<th>Containment design</th>
<th>Probability of significant leak (P)</th>
<th>Relative cost (C)</th>
<th>(P) / (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single HDPE Liner</td>
<td>0.039</td>
<td>1</td>
<td>0.039</td>
</tr>
<tr>
<td>Single composite liner</td>
<td>0.0024</td>
<td>2</td>
<td>0.0012</td>
</tr>
<tr>
<td>Double HDPE Liner</td>
<td>0.0026</td>
<td>2.5</td>
<td>0.00104</td>
</tr>
<tr>
<td>Double composite liner</td>
<td>0.0008</td>
<td>4</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

From Table 2 it is obvious that double composite liner provides the best money—environmental result relationship.

4 Evaluation of operational issues

Using a methodology that frequently is applied in industrial plants, a detailed risk analysis of possible landfill accidents and hazards can be implemented. After the creation of the conceptual model for the activity of interest, such a risk analysis comprises of three steps [14].

First, all the possible accidents must be recorded. An Operability Analysis is applied according the procedures usually implemented in industrial processes. Operability Analysis consists of an evaluation of causes and consequences of relevant processes variable deviations in each significant activity.

Second, a qualitative evaluation of the occurrence probability is estimated, for every accident found out in Operability Analysis (First step). Typically probabilities are classified as Unlikely accidents (U), Low Probable accidents (LP) and Likely accidents (L).
Third, a consequence evaluation follows for every accident. Evaluation of consequences can be implemented in quantitative or qualitative terms, depending on the availability of data and the know-how of the risk assessor. An typical qualitative classification of sequences includes Small (Sm), Serious (S) and heavy (H) consequences.

Table 3 show a typical Risk Matrix associated to waste volume and leachate of a landfill.

<table>
<thead>
<tr>
<th>PROBABILITY</th>
<th>Likely</th>
<th>Low probability</th>
<th>Unlikely</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subsidence of landfill bottom</td>
<td>Bad smells diffusion</td>
<td>Presence of insects and mice in the landfill area</td>
</tr>
<tr>
<td></td>
<td>Contact between rainwater and leachate</td>
<td>Obstruction of tubes of the leachate drainage system</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td>Serious</td>
<td>Heavy</td>
</tr>
<tr>
<td></td>
<td>CONSEQUENCES</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Consequence analysis and evaluation of causes of each accident can go so far as the data and the event breakdown allow. A similar methodology can be used for health and safety effects. The establishment of a suitable information system that will provide reliable statistics should accompany an initial operational risk analysis. By this way the probabilities that correspond to each accident will be based on real data, after some years of operation.

5 Development of waste acceptance criteria

At 21st of March 2002 a working document [15] regarding waste acceptance criteria in different kinds of landfills was launched from Brussels. This document provides waste acceptance criteria for inert, non-hazardous and hazardous waste landfills. It is widely known that waste acceptance criteria was
one of the most difficult issues during the negotiations regarding the landfill directive 1999/31[16]. Due to the difficulty and the complexity of the problem, a risk-based procedure was involved in order to provide a scientific basis against the contradictory national interests.

This approach consists of several consecutive steps [9]. Initially, a decision is made concerning the primary targets or points of compliance (POC) like the quality of groundwater at one or more points downstream of the landfill. Quality criteria are then selected for the groundwater and the physical characteristics of the landfill and environment scenarios are selected and described. Environment scenarios include net infiltration rate and a hydrogeological description of the unsaturated and saturated (aquifer) zones upstream, below and downstream the landfill.

The source of various contaminants is subsequently described in terms of the flux of contaminants as a function of time based on leaching data and the hydraulic scenario defined. Then the migration of contaminants through the unsaturated zone into the groundwater and through the aquifer to the POCs is described.

The next step is to select and fit one or more groundwater flow models in order to simulate contaminant transport through the base of the landfill and into saturated and unsaturated zone.

For each contaminant and POC an attenuation factor (the ratio between the source peak concentration and the concentration that the model predicts at the POC) is estimated. The attenuation factors are then used for a ‘backward’ calculation of the values of the source term corresponding to the selected groundwater quality criteria for each contaminant at a particular POC. The final step consists of transforming the resulting source term criteria to a limit value for a specific test.

6 Conclusions

Risk analysis has become a central component in modern waste management systems. The extended use of risk analysis in landfill procedures, from strategic planning up to post closure, produces a number of advantages for all the involved parts. The output of the risk analysis procedure is an objective, rather than a subjective, assessment. The ability to provide numerical values, although there are uncertainties, creates a rational basis for the estimation of the issues of interest.

Even if the output does not seem adequate, due to wrong assumptions or not fitted conceptual model, alternative models and assumptions may be applied. The effect of such changes to the overall result of the risk analysis allows the operator/ regulator to assess the sensitivity of the model and to select the most appropriate for each case.

The cost effectiveness of alternative designs and operational practices can be evaluated. Thus, limited financial resources can be targeted to optimize the performance of the containment system and the operational standards.
Quantitative risk analysis provides a way to estimate the real environmental protection of each measure. Any groundwater model can utilize the output of such an analysis and simulate the contaminant transport. Obviously, the main limitation to risk analysis in landfills is the lack of reliable data for several landfill components. Uncertainty is an internal part of any landfill risk analysis. The use of expert panels gives a safe basis for the necessary estimations, but only the systematic monitoring and non-destructive testing in large timescale can really produce the data needed. It is believed that the application of the landfill directive 1999/31 EC will promote a more generalized use of risk assessment in landfills, especially to:

- liner design
- leachate collection and treatment design

References

Waste Management and the Environment


