

# **Hazardous Wastes Problems in Iraq: A Suggestion for an Environmental Solution**

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## **Abstract**

Iraq passed through many destructive wars where the country infrastructures have been destroyed. Consequently, various types of hazardous wastes generated from 1991 and 2003 wars are exposed in different parts of Iraq without any aspect of human and environment considerations. Contaminants are found in the form of contaminated rubble with depleted uranium (DU). Landfill disposal is still an economical and vital solution that should serve between 300-1000 years for confining hazardous wastes like DU. The longevity of a hazardous waste landfill is mainly controlled by clay based liners. There are many factors affecting the performance of clay liners. These factors were discussed. The main requirements of hazardous waste landfills were listed according to USEPA and German regulations. Finally, the main aspects of landfill siting criteria in Iraq were suggested.

**Keywords:** hazardous wastes, depleted uranium, landfill, clay liners, site selection

## **1 Introduction**

Hazardous wastes have many national definitions which fall into two major groups; characteristic wastes and listed wastes. Characteristic wastes are known to exhibit a hazardous action like ignitability, corrosivity, reactivity and toxicity. Listed wastes are considered the out product of specific industrial wastestreams. They include F, K, P and U-list, [1]. Radioactive and chemical wastes in Iraq are considered hazardous according to the Environmental Protection Agency (EPA) and European Community (EC) criteria. Depleted uranium (DU) falls under Low-Level radioactive Waste (LLW) according to United States Nuclear Waste Policy Act. LLW defined as “*Radioactive waste that is not high-level waste, spent nuclear fuel, transuranic waste, or uranium or thorium mill*

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*tailings*” [2]. DU is less radioactive than uranium by 40% which is a byproduct of the nuclear enrichment processes. DU is genotoxic; it chemically alters the DNA resulting abnormally high activity in cells leading to tumor growth [3,4]. The research of using DU as armor-penetrating ordnance began in early 1970s by US army because of its extreme density [5,6].

Iraq passed through many destructive wars where the country infrastructures had been destroyed. Consequently, various types of hazardous wastes were left behind and exposed in different parts of Iraq without any aspects of human and environment considerations, Figure 1. The nature of hazardous wastes was either radioactive or chemical. These wastes were generated from 1991 and 2003 wars which are found in the form of contaminated rubble with DU used by the American and allied forces in Iraq [5,7] or in the form of chemical wastes produced as a result of bombing Iraqi chemical facilities belonging to Iraqi Ministry of Defense or some of industrial organizations like Al-Mishraq sulfur factory in Ninawah governorate. IAEA reported many contaminated sites with different levels of waste radiations ranging from LLW to High-Level radioactive Waste HLW [8,9]. Another type of contamination was the decommissioning of the destroyed Iraqi nuclear facilities which were considered to be hazardous with different levels of radiation. They are Al-Ramah site in Jezira area west of Mosul city, Adaya site located 50 km west of Mosul city containing 3 tons of yellowcake and uranium oxide produced from Al-Ramah site and 80 tons of destroyed equipments, Al-Tuwaitha nuclear research center which was totally destroyed during 1991 war and further damaged in 2003 war. Al-Wardia site contains two types of radioactive pollutants, a ready to use material including the yellowcake beside 3 tons of stored waste in plastic containers. Furthermore, Al-Qaim, Geo-pilot Plant, Tarmiya, Rashdiya, Al-Atheer were considered as contaminated sites according to the Iraqi Ministry of Environment and IAEA, [10,11].

To sum up, the existing radioactive wastes in Iraq estimated to be more than 500 tons of solid wastes and 270 tons of liquid wastes without considering the aforementioned numbers of contaminated scrap and rubble [8]. It was also reported by the Iraqi Ministry of Environment the existence of 152 heavily contaminated sites in different parts of Iraq which were classified as extremely polluted with hazardous wastes. Unfortunately many of them are open for biotic receptors [12].

In 2004, the Iraqi Government requested the assistance of IAEA for solving the contamination problem. On this basis, the IAEA responded to assist the Iraqi government by adopting the first basic step to evaluate the contamination problems covering all parts of Iraq and putting all related problems into consideration, like the decommissioning project of the Iraqi x-nuclear facilities [11]. Consequently, many health related problems were documented in different parts of Iraq like cancer and abnormally born infants [5, 12, 14].

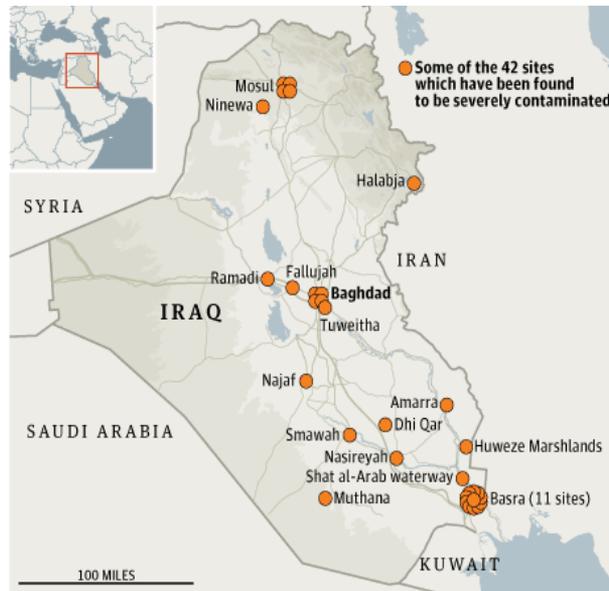


Figure 1: Contaminated sites in Iraq with different levels of contamination with hazardous wastes, After [13].

## 2 Disposal of Low-Level Radioactive Waste

The main objective of hazardous wastes disposal systems is the isolation of wastes from biosphere for the period required to ensure no potential future releases of harmful substances would result. Time scale for the disposal systems depends on the life-time scale of the waste. Radioactive wastes are known to have long-life radioactivity, unlike the chemical wastes. LLWs and short-lived ILWs (intermediate level radioactive wastes) are usually contained in near surface landfills. On the other hand, HLWs have much longer life-time (more than 10000 years) where they disposed in deep geological repositories [15]. In Iraq case however, the time frame for the radioactive wastes varies due to the waste as they vary between LLW to HLW. If a near surface burial system is adopted, this system can usually contain a LLW and short-lived ILW which require a time frame performance between 300 to 1000 years [16].

Land disposal of hazardous waste is still the lowest cost of the available technologies, [17]. These landfills are mainly composed of resistive final cover (including top liner), a bottom liner and leaching removal and collection system (LRCS). Final covers usually comprise of multi-layers; a surface layer (with/without a vegetative cover), protection layer, drainage layer, hydraulic/gas barrier layer, and foundation layer. The main objective of well-engineered final cover is to 1) control water percolation to the wastes, 2) control the release of gases and 3) to function as a physical buffer isolating the wastes from biotic receptors [18, 19]. A properly designed covers will minimize or eliminate water percolation into waste body, hence minimizing or under some conditions eliminate the need for bottom liner [20]. Liners are considered as the main element of any landfill which are usually constructed from compacted clays or may be used as geosynthetic clay sheets. Compacted clay liners should be designed to function with low hydraulic conductivity (K) which is controlled by the proper selection of raw materials and

compaction density. Clay liners constructed from native material, near to landfill site, could be compacted alone or mixed with fillers like sand, gravel or even synthetic filler for better performance [19, 21].

### **3 Long-Term Performance of Clay Liners**

A hazardous waste landfill should serve with the minimal maintenance according to the USEPA and German regulations. The longevity of landfills depends mainly on clay based liners which is affected by many factors.

#### **3.1 Cyclic Stressing Mechanisms**

Wetting/drying and freezing/thawing cycles can largely affect hydraulic conductivity of the clay liners. Wetting/drying cycles generate desiccation cracks which might cause a decrease in the functionality of most clay liners. Smectite (a group of expanding clay minerals) rich clay has a unique character; self-healing. Boynton and Daniel reported that clay liners subjected to 28-56 kPa can start self-heal the desiccation cracks resulted from cyclic wetting/drying (swell-shrink) [22]. Swell-shrink defects could be reduced by the inclusion of granular materials (silt, sand or gravel) with the clay used for lining.

On the other hand, freezing/thawing cycles might be capable of increasing the hydraulic conductivity by 50-300 folds for only 10 cycles [23]. The freezing of fine grained soils, like silt and clay, will produce ice lenses which will cause local densification of the soil structure forming aggregates filled with ice occupying pores. On thawing, this will yield low effective stress along the frozen depth of the soil. Knutsson et al. concluded that permeability values are directly controlled by the initial void ratio. Dense soil structure may yield an increase in permeability, whereas permeability may decrease for loose soil skeleton due to local densification [24]. Freezing degradation mechanism might be avoided by placing a protective layer having a depth greater than the maximum frost depth over the top liner [25].

#### **3.2 Biological Activities**

Microorganisms present in the soil can adversely affect clay hydraulic properties by increasing organic matter. Nutrients availability, temperature, oxygen, moisture and osmotic pressure are factors creating excellent environment for their maximum performance of alteration, this process is called biotransformation of clay minerals. When a clay mineral is attacked by bacteria, this will dissolve the bonding energy between the atoms that makes up a clay mineral leading to a dissolved clay mineral. However, many chemical compounds are considered toxic to many microorganisms depending on contact time and concentration [15].

#### **3.3 Chemical Attack by Waste Leachate**

Hazardous wastes generally stabilized prior to disposal in landfills, e.g. chemically. The chemical attack by leachate must be considered as it causes serious defects. This is mainly focused on bottom liner where it is considered as the final defense line. Acids have been

reported to dissolve alumina while bases capable of dissolving silica. Clay minerals contain large quantities of both silica and alumina, thus they are susceptible to partial dissolution by either acids or bases. Some acids like hydrofluoric and phosphoric acid aggressively dissolve clays. Leachate with  $\text{pH} < 3$  and  $> 11$  have the most affecting factor on clays [20, 21, 25].

### **3.4 Gas Generation**

Top clay liners should be designed for the upcoming heave due to gas generation. The gas movement through the top liner has two effects; oxygen migrating into waste body through the top liner may speed up the release of metal ions due to acidic environment. The other effect is the heaving the entire top cover if the gas conductivity for the top liner is too low. Self-healing of the clay liner should be able to close gas channels. From a practical prospective, 40-50% smectite is sufficient to self-heal clay liners after gas penetration [20].

### **3.5 Piping and Erosion**

Water accumulation over the liner will increase water pressure that may reach critical values causing piping and erosion of fine materials. Comprehensive laboratory testing on smectite rich soil indicated that a hydraulic gradient (water pressure/liner thickness) between 20-30 m/m is capable of doing damage, especially for thin liners like geomembrane. However, compacted clay liners should be thick enough to resist such risks [25]. Risk of piping can also be reduced by well-designed filters surrounding clay liners [19].

### **3.6 Landfill Stability**

Excessive differential settlement under clay liners leads to cracks. This effect is minimized if the clay layer is thick and ductile. The bonding mechanism and inter-particle forces are two major factors controlling the structural stability of the compacted liner. Surface inclination will change when not considering the settlement and might produce a lake on the hazardous waste landfill. Another stability issue is the liner slope stability. Breakage due to slope failure will lead to pollutants release. The slope instability can be caused by water addition to the lining system or cracks can be produced due to seismic activity. Slope stability must be insured by liner shear strength and selecting appropriate side slopes. Most modern landfills have side slopes in the order of 3:1 (H: V) ratio [19, 21, 25].

### **3.7 Intrusive Events**

Hazardous wastes landfills are usually constructed away from human activities. There will be a big chance of various types of animals invading the top cover seeking for food or shelter. In USA, it was documented that the harvester ants excavated the protective layers to depths of 2-4 m. Further, vegetation growth on the top soil cover is an important matter that engineers should be aware of. Plant root system penetrates the soil seeking for water and neutrons. One should pay attention to the ability of roots to establish cracking

in asphalt and concrete pavements. Root penetration could reflect 1) mobilization of contaminants to the surface by roots, 2) induction of water movement to the buried waste. In Germany, the vegetation growth at the top cover was not considered, roots penetrated through the top soil to a depth of 1.6 m causing big problems [27]. Furthermore, when vegetation colonize the top soil, this will lead to significant changes in water run-off that will increase water infiltration rate due to death and decay cycles that will produce organic materials retained at the top. In spite of these defects, one important effect of vegetation presence is the alteration of water balance. Roots seek for water and neutrons from the soil to support growth thus pumping the water out of the soil mass to the atmosphere. Another key of success of plant presence is to hold soil surface (i.e. minimize erosion). Vegetation growth should be controlled (designed) which will also add an aesthetical touch to the landfill [17, 25, 26].

#### 4 Requirements of Hazardous Waste Landfills

Landfill engineers should meet certain regulations when designing final cover, bottom liner and LCRS. Final covers must be designed to function with minimum maintenance and to accommodate settlement and subsidence of the underlying layers. German regulations advice the basal liner system (bottom liner system) should function reliably and permanently as the repair will be impossible. The leaching system should be designed so that the leaching hydraulic head on the liner does not exceed 0.3 m. On the other hand, some design approaches advice the construction of the bottom liner system without LCRS for very low leaching productivity especially in hyper-arid regions. However, future climatic changes should be considered because the lifetime service of these structures range from 300 to 1000 years. There are many international regulations concerning the requirements of hazardous waste landfills. German and USEPA regulations were taken here as an example, Table 1, Figures 2 & 3. German regulations mostly fit humid climate regions whereas USEPA regulations are more adapted to hot climates. Both of them focus on constructing a tight bottom liner. The authors suggest that both regulations might be considered in the design of a hazardous waste landfill in Iraq considering current and future climatic conditions.

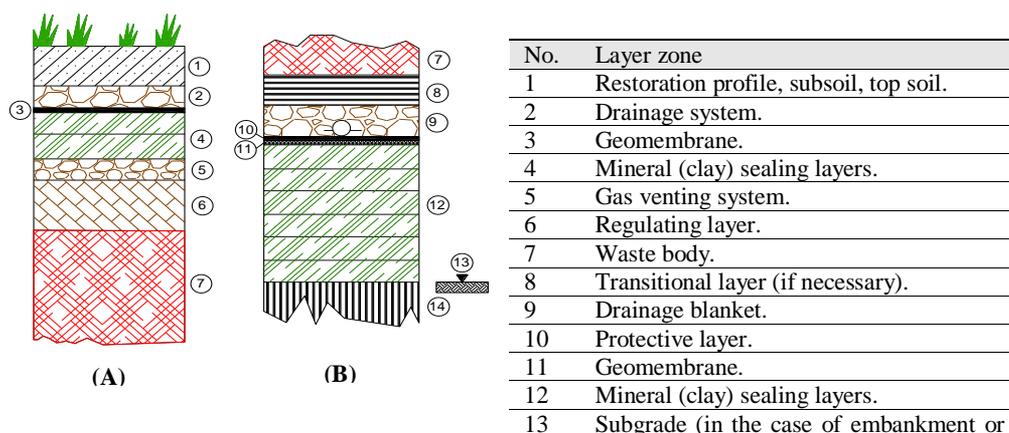


Figure 2: Minimum requirements for hazardous wastes landfills according to German Geotechnical Society, A) Final cover. B) Bottom liner. Modified from [28].

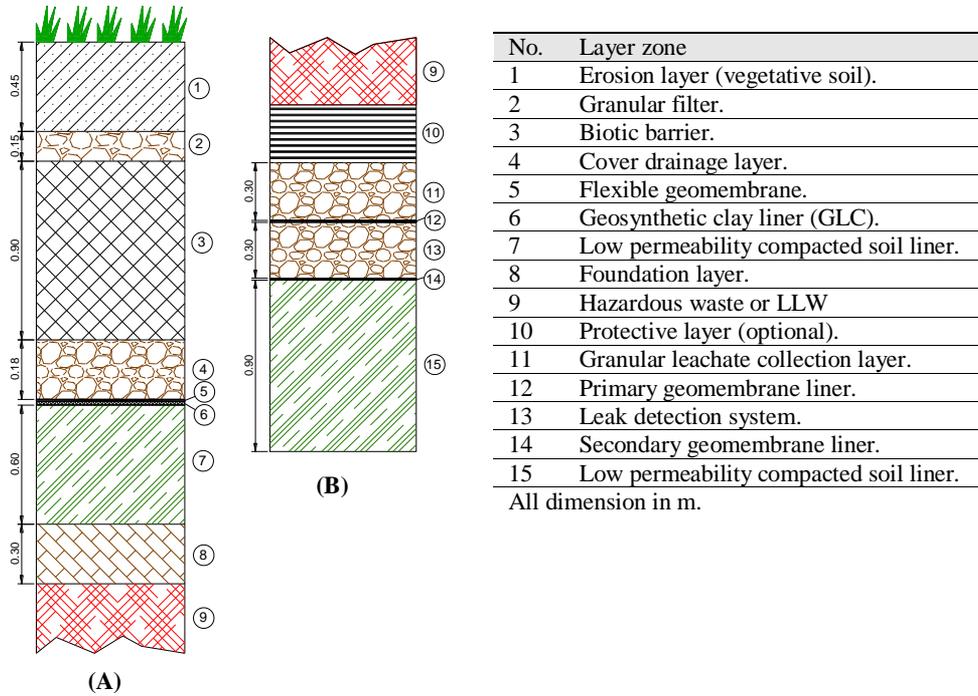


Figure 3: Minimum requirements for hazardous waste and LLW landfills under RCRA 40 CFR §258, A) Final cover. B) Bottom barrier. Modified from [29].

Further, efforts should be focused on designing as tight as possible top liner instead the bottom liner. The top liner will control water percolation while the bottom liner is considered as the final defense line.

### 5 Suggested Site Selection Criteria of Hazardous Wastes

Site selection process is the key factor to a successful design of an engineered hazardous waste landfill. It should be planned on a stable geological bases and a little sensitivity toward the environment and biotic receptors in case of escaped contaminants. Three main aspects should be considered: environmental, geological and finally economic and social criteria. Failure scenario analysis should be done, e.g. the possibility of the contamination of surface and ground waters, wildlife and public Areas. In this context, authors believe that the requirements listed in Table 2 could be considered as the main aspects for selecting a landfill site in Iraq confining hazardous wastes.

Table 1: German and USEPA regulations for final cover, bottom liner and LCRS

Component	German regulations	USEPA regulations
Final covers	Regulating soil layer (0.3-0.5 m), gas collection, compacted clay liner ( $K^{\S} \leq 1 \times E-9$ m/s) or geo-synthetic clay liner, geo-membrane, drainage layer (0.3 m) with $K \geq 1 \times E-03$ m/s inclined by 5% and not greater than 3:1, a thick soil cover of 1.5-3.0 m suitable for humid areas.	Geo-membrane, geo-synthetic clay liner (GCL), low permeability soil layer (0.6 m) with $K \leq 1 \times E-08$ m/s, granular drainage layer (0.3 m) thick with 3:1 slope, a layer of rock or other mechanically resistant material.
Basal (Bottom) liner system	Sealing system ( $K \leq 1 \times E-10$ m/s) with thickness $\geq 1.5$ m, geo-membrane, a protective layer to prevent puncture of the geo-membrane and usually constructed from a 0.1 m sand layer. Drainage layer constructed from coarse grained material, thickness 0.3 m, $K \geq 1 \times E-03$ m/s.	a double liner with a single geo-membrane (primary liner), a drainage layer, a geo-membrane and low-permeability soil composite (secondary liner), compacted clay liner with $K \leq 1 \times E-09$ m/s, leak detection system.
LCRS	Drainage blanket (0.3 m thick) with $K \geq 1 \times E-03$ m/s, protective layer, drainage pipes, collection and monitoring shafts (chimneys).	Drainage layer of clean sand or clean gravel with K value between $1 \times E-05$ to 1 m/s, filters, cushions, sumps and pipes.

<sup>§</sup> Hydraulic conductivity

Table 2: Main aspects suggested for sitting a hazardous waste landfill in Iraq

Criterion	Description
Environmental	Ground water quality: Areas with saline water is suitable over high quality water.
	Groundwater flow direction: The area should be located away from downstream communities.
	Groundwater flow gradient: Low flow gradients areas are suitable.
	Floodplains: A 100-year flood event must be considered to avoid disturbance and washout of the landfill final cover.
	Water Table: Groundwater Table should be deep enough to avoid capillary effect.
	Distance to surface water: Rivers or streams and lakes or ponds, the area should be located at least 3000 m for rivers and 2000 m for lakes.
	Wetlands: These areas must be avoided.

Geological	<p>Topography: The selected site is better to be convex in relation to the surroundings to ensure better drainage characteristics.</p> <p>Sub-soil properties: The selection should be based on soils having low hydraulic conductivity, high cation exchange capacity and high pH values.</p> <p>Depth to bedrock: The deeper the depth, the better the selected area will be.</p> <p>Seismic conditions: Seismic intensity should be as low as possible.</p> <p>Reservoir areas should be far from the site to avoid induced seismicity.</p> <p>Faults: Active faults affecting landfill stability should be avoided.</p> <p>Karst terrains: Areas with soluble rocks (limestone and dolomite) should be avoided as it may cause hidden cavities.</p> <p>Mass movement: Areas sensitive to movement due to gravitational events should be avoided</p> <p>Sand dune movement: Areas subjected to sand dunes swarms should be avoided.</p> <p>Nature of rocks: Soluble and jointed rocks should be avoided.</p>
Economic and Social	<p>Landfill capacity: Sufficient capacity to meet current and future needs.</p> <p>Infrastructures availability: Main roads and power supply lines should be considered.</p> <p>Habitation: The site must be located at least 500 m away from nearest occupied area.</p> <p>Public acceptance: The selected area should not adversely affect public health, quality of life, local land and property values.</p> <p>Distance to primary highways: Visual impact related with a landfill from adjacent highways must be considered.</p> <p>Land-use: The landfill should be located in areas of low economic value.</p>

## 6 Conclusions

Considering the contamination fact with different types of hazardous wastes (e.g depleted uranium), near surface landfill is an economical and vital solution considering the amount of wastes. Basic requirements of hazardous waste landfills that could match Iraqi current and future climate could be based on USEPA and German regulations. Efforts should be focused on designing as tight as possible top liner instead the bottom liner. Landfill designing process beside site selection criteria are two important factors controlling the landfill longevity. The suggested site selection criteria by the authors might be suitable and could be adopted as a first basic step for resolving contaminations problem in Iraq.

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