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Isolation of Radioactive Military Wastes in Iraq

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Abstract

Iraq has been subject to a series of wars for more than fifty years, the latest one leaving large amounts of wrecked tanks, vehicles, weapons and ammunition. A considerable part of the waste has the form of, or contains, depleted uranium (DU), that is concluded to have cancerogenic effects through its radioactivity and toxicity. The DU exists in significant concentrations in areas where combat took place, mostly in and around the cities of Bagdad and Basra, the total number of particularly encountered areas being about 15. The way of long-term isolation of DU that is proposed in this paper is to construct relatively simple landfills of sandwiched contaminated soil and clay or clayey soil, covered by sand/gravel and erosion-resistant coarser material on top. The very low annual precipitation and long draught in the deserts, implying significant evaporation, means that the system of tight soil interlayered with contaminated soil, embedding wrecked military objects, minimizes percolation and release of DU, keeping it adsorbed on the finest soil particles. The clay-based material must be composed in a way that, i/ desiccation fractures are not formed in periods of long draught and ii/ not swell uncontrolled and loose strength in wet periods. The DU-contaminated soil is proposed to be scraped off and transported in closed trucks to four desert sites where landfills of the sandwich-type are proposed to be constructed.

Keywords: Depleted Uranium, Iraq, Landfill, military waste

1 Background

Iraq was declared independent kingdom in 1932 and was proclaimed republic in 1958. Until recently the country has been ruled by military regimes and been involved in three major wars, of which the first was the 8 year war with Iran, followed by a 2 year conflict with Kuwait, ending by interference of UN coalition forces. The UN Security Council required Iraq to scrap all mass destruction weapons and long-range missiles but the regime did not comply with this, which led to the US-led invasion in 2003**.** The war,

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which ended formally in year 2003, involved use of armour-penetrating ammunition with extreme weight and density achieved by the content of depleted uranium (DU). It is a by-product of the enrichment of natural uranium for producing nuclear reactor-grade uranium, and is placed to form the tips of armour-piercing shells because its density is 1.7 times higher than that of lead. On explosion of bombs and other weapons, the DU oxidizes into microscopic particles that contaminate the ground. These particles can easily be dispersed and taken up by lungs, bones and blood, leading to cancer and permanent health hazards of humans of any age. This is concluded from illnesses of more than 30 000 soldiers following the Gulf War [1]. Dispersed DU contaminates the terrain in certain local areas and exposes the population to danger and hazards at physical contact with wrecked weapons and soil, being spread out by wind forming aerosols.

The objective of this paper is to describe how safe deposition of DU-contaminated soil and military waste can be made to a reasonable cost using simple modern landfill technique.

Information is gathered from open sources such as interviews with engineers, geologists and representatives of the Iraqi Ministry of Water Resources, scientific papers like doctoral thesis, reports prepared by international organizations such as the UN, FAO and the World Bank, etc.

2 Is there a Need for Cleaning DU-contaminated Areas?

The toxicity of DU is manifested by several health studies [2] and the ban on DU weapons passed by the European Parliament. Detailed studies of the impact of DU on humans have been conducted by a number of investigators who analyzed various parts of human bodies [3-13]. They found that DU is organotropic and becomes integrated in organs such as skeletal tissues and accumulates in the kidney, reproductive system, brain and lung with verified genotoxic, mutagenic alterations. There is also evidence of the mutagenic effects of alpha particles and alpha radiation [13]. It is claimed that DU, although being 40 % less radioactive than natural uranium, can be “genotoxic” and chemically alter DNA. It can easily enter the body through the skin and the lungs, and eventually cause tumours and leukaemia, and damage the immune systems. This is because the fineness of DU" can easily make it enter the human body. Traces of DU have been found in people even 20 years after initial exposure.

Physical abnormality is increasing in Iraq after the Gulf war. Thus, 5.2 % of 13191 pregnancies had some form of abnormalities compared to 3.5 % before the Gulf war [14]. Following the invasion of Iraq thousands of cancer cases have been reported among Iraqis and the IAEA document predicted the death of half a million Iraqis and it is believed to be caused by toxic weaponry [15].

There is, in conclusion, clear medical evidence of the health risk of uptake of DU in human bodies and considering the $4.5\ 10^9$ year half-life time [16] there are strong reasons for removing DU remnants from contaminated areas and place it on disposal sites, providing safe isolation from the population. It is worth noticing that the US Navy and Marines have abandoned depleted uranium ammunitions in light of their potential health hazards [17].

3 Where are the DU-contaminated Areas Located?

There are at least 300 contaminated sites in Iraq of which at least 40 have high levels of radiation. About 10 of these are near Iraq's biggest towns, including Bagdad, Basra, Najaf, and Falluja. Others are located close to Mosul and Ninewa in the north and Halabja in the northeast. Bagdad, Ramadi, Falluja and Tuweitha represent sites in central Iraq while the rest, Najaf, Amarra, Dhi Qar, Huweze (Marshlands), Nasireyah, Shat-el-Arab waterway, Muthana and Basra, are located in south-eastern Iraq.
In some of these areas, the Iraqi government together with the American and allied forces have carried out clean-up operations and soil replacement. The Uranium Medical Research Centre (UMRC) has made comprehensive surveys in Bagdad, Basra and Nasiriya.

4 Cleaning Operations

In 2003, U.S. military engineering units and Iraqi contractors, escorted by U.S. army security forces, removed and piled up shallow soil by bulldozers and dump trucks and transported contaminated sand/silt material to disposal sites. Fine dust was then spread from the transports and fell back inundating square kilometres [18]. The contaminated soil was dumped in berms and filled in caissons. The battleground in certain areas was covered with piles of sand and bombed-out building debris which was trucked into the site and spread out over the combat areas. This cover-up was careless and incomplete, leaving radioactive kinetic penetrators, wrecked tanks and heaps of spent and unused ammunition exposed. Several of the damaged tanks, cars and artillery components were moved to the "tank graveyards" in Auweirj and to occupied airports. However, considerable amounts of disabled tanks and armoured assets remain in secondary roads, backyards and farmland.
The Nasiriyah area, investigated by UMRC, was defended by an Iraqi heavy armour group. Here, main battle tanks of Russian origin had been dug-in for defence and some of them could be pulled up at the end of the war and moved to a coalition-occupied airport. Nevertheless, a UMRC team investigating the area found three remaining tanks being radioactive. Geiger-Mueller counts in the area were several hundred times higher than background values and residents of the houses within 30 m distance from the tanks were warned to come close.
The largest concentration of disabled Iraqi main battle tanks is in the Abu Khasib area, where the British led the advance on Basra. The British army has warned residents and recycling teams that the tanks are radioactive, but has not taken steps to clean the area from radioactive objects [18].

5 Iraq's main Topographic and Geological Features and Climatic Conditions

5.1 Topography and Hydrogeology

The mountain region in the north has local altitudes of more than 3000 m. The average annual precipitation here is about 1000 mm with snow covering the peaks. This region supplies the big rivers Eufrat and Tigris with water that also provides the southeastern part of the country with a high groundwater level and very good opportunities for agriculture and fruit production. In the western part, desert extends from Al-Kayem (Iraqi Syrian border) all the way down to Al-Salman (Iraqi- S. Arabian order), i.e. a region with an approximate area of about 168,000 km^2. Deserts of around 100,000 km^2 are also present in the north and bare hills southeast parts, near the Iranian border. In the western desert area, the groundwater level is located at a depth of more than 200 m, while it is shallower in the northeastern and south-eastern areas. The reason for the geohydrological conditions in the central and southern parts of the country is the distribution of the annual precipitation, which normally ranges between 200 and 500 mm and is less than 200 mm in the western desert areas.

The average air temperature in central and southern Iraq is 5-10°C in wintertime and 25-35 °C in summer. It thus causes desiccation and very dry conditions in the desert areas. Winds can be strong and cause erosion and transport of fines over large distances.

5.2 Geology

The geological condition of Iraqi bedrock is complex and mirrors the evolution of the earth crust in this part of the world, implying comprehensive faulting and folding. Bedded salt with a thickness of several tens of meters is found over large parts of western and southern Iraq with sedimentary rock, mostly sandstone and limestone, below the salt. The sedimentary deposits are locally several thousand meters thick [19, 20] and with a pore volume containing huge amounts of oil and gas. The shallow part of the underground in the desert areas is different as well as in the north/south oriented part extending from the mountain area in the north to the former and present delta land in the south-east. The sandy/silty topsoil in the deserts can be cemented as in Sahara, while the central part where the big rivers Eufrat and Tigris flow contains soft, normally consolidated and often organic soil. The river-transported soil has accumulated where the flow rate has been temporarily low by which small islands were formed, but erosion and meandering has caused variation in the topography and deposition of clay where stagnant conditions prevailed. The clay layers have a varying thickness and granular composition, often intercalated with silt, and the mineral content varies from hydrous mica (illite) to smectite-rich material. The clays play a key role in the reclamation of contaminated terrain by serving as tight isolation and binder of soil and waste.

6 Proposed Principles for Reclaiming DU-contamined Soil and Wrecked Armour in Iraq

6.1 Disposal Sites

The climatic, hydrological and geological conditions make the deserts in the western, north-eastern and south-eastern parts of the country suitable for the deposit of DU-contaminated soil and wrecked armour. It is proposed, that the waste should be brought from the fifteen sites that are most heavily suffering from DU-debris to a small number of disposal sites. Here it is proposed two sites in the western desert area, one in the northeast, and one in the desert northeast of Basra. These in total four disposal sites, can be of different size depending on the amount and type of waste. The largest amounts of waste are located in the Bagdad, Ramadi, Falluja and Tuweitha areas for which two major disposal sites some 300 km west of Bagdad should be constructed. A smaller site in the northeast should be built for the waste from Mosul, Ninewa and Halabja, and a major one in the southeast for the waste from Najaf, Amarra, Dhi Qar, Huweze, Nasireyah, Shat-el-Arab, Muthana and Basra. Some transport of waste from Basra to the proposed two major sites in the western desert area might be necessary.

6.2 Excavation and Transport Issues

Excavation of the DU-contaminated soil and solid waste consisting of unarmed ammunition and disseminated tanks, canons and vehicles is proposed to be made by bulldozers and placed on trucks for transport to the respective site. The trucks have to be covered for minimizing the risk of dispersion by wind during the transportation. The soil material should preferably be wetted before loading.

6.3 Selection of Sites with Respect to the Long-term Performance of the Isolation

The principle followed in locating landfills of hazardous chemical waste is to select an elevated area like large stable ridges and plateaus with inclined top surfaces. If the area is very flat, landscaping can create artificial hills by bringing suitable sand/gravel soil on site and compacting it layer wise by the use of effective equipment like vibrating or excentric rollers. By doing so, and equipping the disposed waste with a tight and erosion-resistant top cover, all or the dominant part of precipitated rain will run off and be discharge to the surrounding desert soil. The infiltrated water in the ground will evaporate with exception of moisture that is held by capillary forces in the soil. Insignificant amounts of water will enter the disposed waste if the top cover is sufficiently tight, which is hence an important design criterion.

6.4 General Design Principle of Landfills

Top covers of waste piles conventionally contain a drain layer over a low-permeable clay liner that usually contains smectite minerals. The rate of percolation of the liner, which may require tens of years to become water-saturated, determines the downward transport of ions released from the underlying waste to and through the bottom clay liner. The percolation rate is controlled by the composition and density of the upper clay liner, which should be as tight as possible. This implies a high density, but this is associated with a high swelling pressure that must not exceed the effective overburden pressure. A bottom clay liner is a less effective and reliable barrier since cation exchange from originally sorbed sodium to iron or calcium can cause a significant increase in hydraulic conductivity and thus percolation rate. Chemical attack on the clay can also be caused by electrolytes in the percolate. Still, many landfills have both top and bottom liners. Figure 1 illustrates a common design principle of landfills.

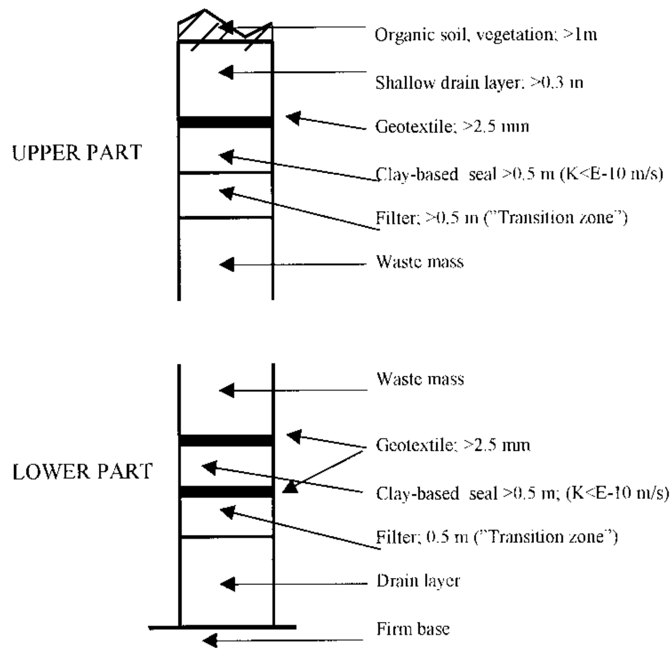

Figure 1: Schematic profile of isolated waste pile (German type). K is the hydraulic conductivity [21].

6.5 A Design Suitable for Iraqi Disposal Sites of DU Contaminants

Ordinary landfills of toxic waste have to be designed for performance in a few hundred years while those built for isolating DU-contaminated waste requires longer operative life-times, at least some tens of thousands of years. The cost aspect is important as well. Thus, while disposal of hazardous waste in the EU implies considerable cost, the DU-waste disposal in Iraq must be as cheap as possible. It is hence important to minimize length of transportation of waste and soil for constructing the landfill and to use soil that is available with only minimum processing and refinement. For saving clay, which is the most precious of the soil components, a principle proposed in an EU project for isolating mercury-rich waste and solidified pesticides []21 can be considered. It implied mixing of smectitic clay and solid waste in weight proportions down to 1:20. However, the facilities for mixing would imply expensive industrial-scale operations and simpler techniques are asked for, like sandwich-type placement of DU-contaminated sandy/silty soil with ammunition and disseminated larger objects mixed in, and interchangeably placed clay layers (Figure 2). The clay, obtained by dredging in rivers or by excavation using large shovels manoeuvred by masts, should have a low water content when placed on the disposal site, which requires spreading out on the ground for drying in the sun as the south-European clay manufacturers frequently do.

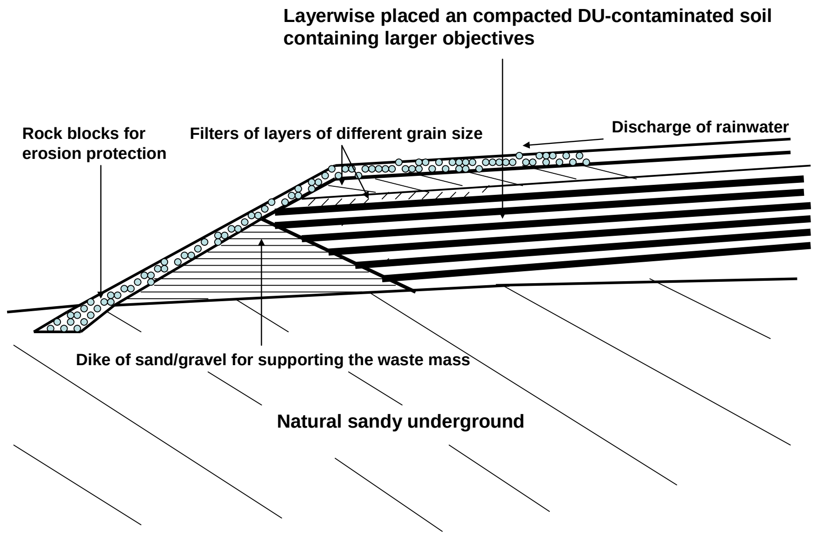

Figure 2: Schematic section of landfill of DU-contaminated soil and solid waste objects.

6.6 Performance of an Iraqi Disposal Sites of DU Contaminants

The erosion-protective function of the coarse top cover is proven by natural evidences, like the Swedish boulder-covered graves from the Bronze age and a large number of stone walls serving as erosion protection of river banks and slopes. Resistance of slopes to erosion has been studied by analyzing ancient mounds in China in order to find long time erosion resistant slope design criteria [22, 23]. Mounds constructed by loess in desert like climate as proven to be erosion stable with slope angles being higher than 30°.

The filtering function of the underlying gravel/sand/silt for minimizing particle transport driven by percolating water is also demonstrated by natural evidences like percolated moraine ridges, and by numerous laboratory and field tests at various technical universities and institutes[24, 25].

The clay layers play a most important role by being buffers in the wetting/drying process that will take place as a function of infiltration of rain and desiccation by evaporation in dry periods, and by sorbing cations released from metallic waste. Capillary forces play an important role in the silty soil contacting the clay as well as in the clay by speeding up wetting and delaying desiccation. The uppermost clay layer is located deep enough to maintain a rather constant amount of pore water throughout the year and it is valuable if smectite minerals form some 20 % of the total mineral content of the clay for guaranteeing self-sealing at wetting after a long period of draught. Moisture may migrate through the underlying DU-contaminated sandy/silty soil layers by surface diffusion [26] and migrate downwards to the next clay layer that will undergo wetting. However, this clay layer is not expected to become completely water saturated. Further downward water migration will not take place unless this second clay layer is almost fully water saturated. In summary, there will be a continuous series of cyclic moisture migration events in the vertical direction, leading to a time-dependent variation of the water content in the upper part of the series of layers.

The described design principle, which can be applied for constructing deposits with a height of several tens of meters, will provide sufficient tightness to prevent percolation of water through the system of layers and hence fulfil the requirement that contamination of the underground by released DU will not take place even in a very long time perspective.

6.7 Special Aspects

While construction of a DU-repository in EU countries would make it possible to select soil materials with properties that do not vary much, the limited access to suitable clay materials may lead to significant variations in grain size distribution and clay mineral composition. The design must therefore be such that the landfills become robust and that some lack in material quality can be compensated by more effective compaction and larger clay layer thickness. One should realize that the climatic conditions in Iraq’s desert areas are in fact nearly ideal for establishing DU-disposal sites since the low precipitation minimizes the risk for build-up of high hydraulic gradients that can cause piping in the clay layers [27], and since the ground temperature excludes the risk of freezing, which might cause permanent damage to these layers.

Clays containing expanding minerals like smectite have excellent isolating properties because of the low hydraulic conductivity and ion diffusivity, and because of the cation sorption capacity [27]. The higher the density of clay layers, the better is the isolating capacity. There is a difficulty, however, in that they exert a swelling pressure that makes them expand, soften and become less dense and hence more permeable if the overburden pressure is lower than the swelling pressure. For optimum performance one should therefore select a suitable density, composition and thickness of the clay layers and top cover.

Conversion of smectite to non-expandable minerals, which would greatly reduce the self-sealing potential of the clay, will not take place since the temperature is far below the critical level [27]. Earthquakes can destabilize earthen constructions but the void ratio of the compacted sand, silt and clay components in the landfills can be low enough to keep them intact even if the shocks are of seismic magnitude 6 [28].

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