Comparative Evaluation of International Practice In Remediating Hazardous And Radioactive Waste Sites

By

J. Santiago, D. Gonzales, & J. Caldwell

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COMPARATIVE EVALUATION OF INTERNATIONAL PRACTICE IN REMEDIATING HAZARDOUS AND RADIOACTIVE WASTE SITES

Juan L. Santiago*, Douglas E. Gonzales†, and Jack A. Caldwell‡

* Empresa Nacional de Residuos Radiactivos, S.A., c./ Emilio Vargas 7, 28043, Madrid, Spain.

†/‡ Jacobs Engineering Group Inc.: †125 Broadway, Oak Ridge, Tennessee 37830; ‡251 So. Lake Avenue, Pasadena, California 91101.

ABSTRACT

A series of disposal cells and particularly the covers used to contain radioactive and hazardous waste from site remediation are described. The disposal site locations vary from the south of Spain to the entire United States climatic zones, including the west and the high precipitation regions of the east. While the regulations that govern the design and construction of these many disposal cells and covers vary greatly, it is shown that a similar engineering approach is adopted regardless of the laws that establish performance criteria. It is concluded that the site specifics, including the availability of suitable materials and climax vegetation, are the primary determinants of the design of robust, long-term covers for radioactive and hazardous waste encapsulation. Case histories are used as a basis to suggest a series of international norms or desiderata to govern the design, construction, and maintenance of long-term disposal cell covers. Numerical and analytic pathway analysis plays a key role in the design process and fulfillment of the protection of human health and the environment.

INTRODUCTION

In this paper case histories are used to describe disposal cell designs used in the remediation of sites where the long-term encapsulation of wastes that are both hazardous and radioactive is mandated. Disposal cells with covers for such waste are required in order to encapsulate the waste for long periods of time to protect human health and the environment, hinder intrusion into the waste, prevent inadvertent waste dispersal, control infiltration of water and radon emissions, inhibit waste leaching to groundwater, and limit the distress and damage of the cell by natural forces.

The designer of the disposal cell for radioactive and hazardous waste must consider and account for the nature of the site; characteristics of the waste; the availability of suitable construction materials; and above all the need to protect human health and the environment for as long as practical and possible. In addition, the designer must show that the engineered disposal facility complies with the intent and requirements of local waste management and health protection regulations. Compliance is attained through the use of acceptable and proven analytical and numerical modeling techniques, material and waste testing, and post-construction monitoring to demonstrate disposal cell performance.

In this paper, an approach is set forth, based on a series of illustrative case histories and experience, to designing disposal cells containing both radioactive and hazardous wastes, and at sites where the long term environmental isolation of remediated wastes is needed. Emphasis is placed on the cover, which is considered to be the critical disposal cell component to meet design and performance goals. The disposal cell design requirements expressed in this paper are a synthesis of the authors collective experience and observations acquired though more than fifty years of providing environmental remedial action services to commercial, governmental, and international clients.

CASE HISTORY 1 - SPANISH URANIUM MILL TAILINGS FACILITY

In the south of Spain on the outskirts of the town of Andujar an inactive uranium mill tailings pile was stabilized in place and a cover was placed over the pile. The pile covers an area of 0.4 hectares and has a total volume of about one millions cubic meters containing elevated radium-226 (^{226}Ra) concentrations, and trace quantities or uranium and heavy metals.

The site is on alluvial clays and gravel terraces, underlain by low permeability shale. Most groundwater flow is in the gravels beneath the pile.

The climate of the Andujar area is characterized by low to medium precipitation, abundant sunshine, medium relative humidity (50-70 %), and moderate to high temperatures with large diurnal and annual ranges. The regional climate may be classified as Mediterranean subtropical with dry and warm summer. Most of the precipitation in the Andujar area occurs during the fall and winter. The annual average precipitation is 550 mm and the mean annual potential evapotranspiration in the area reaches 823 mm.

The remedial action plan proposed for the Andujar mill site involved stabilizing and consolidating the uranium mill tailings and contaminated mill site buildings and equipment in place. The actual tailings pile was reshaped by flattening the sideslopes to improve stability. The remediated pile was constructed with four percent topslopes and 20 percent sideslopes, which provide static and dynamic slope stability without requiring excessively large rock to resist erosion.

The pile was covered with a multilayer system to meet the simultaneous demands of erosion control, infiltration control, desiccation protection, biointrusion control and aesthetics. Following is a list of the main performance criteria that defined the design of the cover and a brief description of how those criteria were achieved:

- Protect from wind and waster erosion: provide erosion protection barriers.
- Limit infiltration: provide for evapotranspiration (soil/vegetation), shed water that falls on the pile (drain layers), incorporate low- permeability infiltration barriers (clay, bentonite mixes).
- Control the dispersion of tailings: provide erosion protection features.
- Prevent intrusion by animals and plants: biointrusion barrier.
- Provide desiccation protection: incorporate a zone of random soil, the purpose of which is to increase the thickness of the cover and protect the infiltration barrier from desiccation.
- Improve aesthetics and blending in with the surrounding area: provide for the establishment of climax vegetation.

The cover selected for the Andujar site included, from the top down, the following components:

- A vegetation growth and rooting medium consisting of a layer of random soil, which may also double as protection of the intrusion barrier from potential desiccation during the hot dry summer of Andujar.

- A filter layer of clean sand to prevent migration of the fine particles of random soil into the underlying barrier.

- A biointrusion layer or large gravel and course rock to deter root penetration and impede burrowing animals. Another function of this layer is to provide erosion protection in the event of gully formation in the overlying soil.

- A drain of clean sand to shed water latterly off the pile.

- An infiltration barrier consisting of silty clay.

On the sideslopes increased erosion protection was provided by an additional uppermost layer of soil/rock matrix.

Advantages of this cover include the reduction of infiltration due to effective evapotranspiration, the protection of the infiltration barrier from desiccation and the existence of a controlled zone - the random soil layer - for vegetation that might establish through the soil/rock matrix and help reduce the adverse visual impact of the remediated pile.

CASE HISTORY 2 - WESTERN US RADIOACTIVE AND MIXED WASTE SITES

In the western part of the United States, the evapotranspiration generally exceeds the precipitation. Many areas are desert or semi-desert. Vegetation is sparse and seldom has deep rooting systems. Below are brief descriptions of come of the disposal cells and covers designed for radioactive and hazardous waste disposal cells designed to deal with these conditions.

The first major project is the U.S. Department of Energy's Uranium Mill Tailings Remedial Action (UMTRA) Project. This project involves remediating 24 inactive uranium mill tailings sites in 10 states, primarily in the west, containing up to 5,000,000 cubic yards of radiologically contaminated material. At about half the sites, the radioactive tailings (containing elevated ^{226}Ra, and low concentrations of U and trace amounts of metals, such as V, Mo, As, and V) were removed and relocated to alternate sites; at the other half, the tailings were reshaped and covered in place. In no case were disposal cell liners used. The cover is the only engineered component used to encapsulate the wastes.

At most western UMTRA sites, the cover consists, from the waste up, of a compacted low permeability clay/silt layer that impedes water infiltration and radon flux, a sand layer that acts as a drain, and durable rock to resist soil erosion by surface water runoff from the probable maximum precipitation.

A more robust UMTRA cover was designed and built at the Durango, Colorado site, where the tailings were relocated to an alternate site, and consists, from the waste up, of a radon and water infiltration barrier of silty clay; a layer 25 mm thick layer of bentonite between two geotextiles (Claymax®); a clean sand drain; a biointrusion zone of rock cobbles; a filter layer of gravel; and, finally, a soil layer, the upper layer of which contains abundant gravel to enhance erosion resistance. This cover was selected to enhance infiltration control, and to minimize biointrusion. It has been in place for more than five years, and is performing well: no erosion has occurred, shallow rooted vegetation is growing and seepage from the cell is as modeled during the design process. A cover similar to this has been adopted for a demonstration and trial project at the Hanford Site in the State of Washington for wastes containing a variety of radioactive and hazardous wastes. For that cover, a layer of asphalt is used in place of the Claymax®: otherwise there is no significant difference between the two cell designs.

A cover proposed for remediation of radioactive waste disposal facilities at an extremely arid site in Nevada would incorporate these components, from the waste up, a 1 meter thick layer of soil-cement formed with local sand; a layer of Claymax®; a drain layer of sand formed by washing local soils; a 1 meter thick layer of random local sand; and at the top another 1 meter layer of local soil to which gravel is added to enhance wind and water erosion resistance. Neither good quality rock or clay are economically available at the site. Local evapotranspiration greatly exceeds precipitation, and vegetation is sparse to non-existent. In addition, those responsible for the site have undertaken to perform continual monitoring and maintenance responsibilities. Infiltration control is achieved by evapotranspiration from the upper soil layers; the bentonite layer will limit infiltration of the seepage through this upper layer. Since the bentonite will swell and essentially close up any cracks induced by waste deformation or desiccation, if and as water reaches it, long term transformations of the waste form are not considerations of concern. Biointrusion control is achieved by the thick layer of soil, the soil-cement, and by continual maintenance activities. Wind and water control is achieved by the gravel added to the upper soil layers. In addition, the soil-cement will bridge any voids that may occur as the waste deteriorates.

CASE HISTORIES 3 - MIDWEST AND EASTERN UNITED STATES

Unlike the western United States, the eastern half of the country experiences a surplus of precipitation over evapotraspiration. Grass and trees grow well and grass can be relied upon for erosion control, but tree root growth must be considered in the design of the cover for a waste disposal cell.

The components of a cover for a disposal cell to be built near St. Louis, Missouri for radioactive and hazardous waste would be essentially the same as that built at the Durango, Colorado site. Major waste constituents to be environmentally isolated by the disposal cell are mixed wastes, soils, sludges, and building debris. The similarity of the St. Louis cover to that built at Durango, Colorado is not coincidental, since many of the engineers involved in the Durango cell are now participating in the design of the St. Louis cell. In addition, it is believed that a similar cover meets reasonable and professional design requirements for the particular site.

An variation in the top cover is, however, being considered. The lower components or layers of this alternate cover would be the same as the current proposed cover: ie., an infiltration and radon barrier of silt and clay; a second infiltration barrier; and a geosynthetic layer. On top of this would be placed a gravel and coarse sand drain; a fine sand filter; 1.2 meters of coarse gravel and boulders. The combination of layers plus the underlying layer of filter sand and boulders and gravel would act as an effective impediment to the establishment and growth of trees and other lush vegetation that characterize the area. Observations of a similar material sequence on an old embankment at the site indicate that the vegetation is unable to establish itself in the rock as the seeds, washed down and trapped on the sand do not possess sufficient inherent energy to grow up through the rock layer. The sand and drain layers deprive the vegetation of a reliable source of water and nutrients.

Both the soil cover and the alternate rock upper component cover proposed for the St. Louis cell are currently being evaluated for a new Stabilization In Place disposal cell at a site that contains both radioactive and chemical waste in Pennsylvania. This site is in the same climatic zone as the UMTRA Canonsburg facility. The cover components for the Canonsburg cell, from the waste up are: a radon barrier of silt and clay; a sand drain; rock sized to resist erosion in the event of loss of the overlying soil; 250 mm of selected soil; and well established grass that is mowed regularly. That cover was constructed about eight years ago, and the design features are considered applicable to the new disposal cell. It is performing well: there is no erosion, and annual grass mowing and maintenance activities controls the development of deep rooted vegetation.

ISSUES AND DESIGN CRITERIA

The regulations and standards that governed the design and construction of the disposal cell covers described above vary greatly. Consider for example the design life. The least demanding standard for hazardous waste cells in the United States calls for a commitment of 30 years of monitoring and maintenance; the most demanding stipulates assured performance for up to 1000 years to the extent reasonably achievable. It must be conceded that 30 years is not a design life, because, in reality, after 30 years, the continual satisfactory long-term performance of the disposal facility must be demonstrated to allow the discontinuance of monitoring and maintenance activities and final closure.

Some of the standards do not include performance monitoring and disposal cell maintenance requirement: others specify that acceptable designs should minimize the need for maintenance. Although proper engineering design can minimize the need for <u>extensive</u> maintenance, some level of long-term maintenance and site control may be inevitable. This would require the establishment, implementation, and maintenance of local or national surveillance programs.

Some standards call for a minimum infiltration rate, and specifically mandate the use of geomembranes to attain this goal. However, the U.S. Nuclear Regulatory Commission, as a lead low level waste management entity, refuses to accept geomembranes as the only mechanism for controlling infiltration. Since the integrity of geomembranes with time cannot be assured, the cover may become nonfunctional in the long term. Accordingly, it is suggested that proper infiltration control should not depend solely on geomembranes, but rely on natural materials and other disposal cell design features.

Some of the standards lead inevitably to a need to design for maximum credible earthquake and the probable maximum precipitation and flood. Most disposal cell design standards impose limits on the long term exposure/dose, or risk to humans and the environment. Therefore, the overall siting, design and long-term performance of disposal cells for hazardous and radioactive wastes will require extensive material and risk based analytical and numerical modeling to assess the long-term fate and transport of the encapsulated waste constituents.

RECOMMENDED INTERNATIONAL NORMS

Internationally, the development, interpretation, and implementation of regulations governing the disposal of hazardous and radioactive wastes, such as the period of time over which specified health based criteria should be met for determined land uses, is certainly the result of a compromise and balance between political, societal, economical, and technical considerations. Although the weight placed on each consideration lies within the jurisdiction of the national entities where the wastes are located, the following series of basic norms may be used to guide the decision making process for the proper and necessary disposal of radioactive and hazardous wastes.

- The design life should be as long as economically and institutionally feasible, and certainly no less than 200 years for mixed waste facilities. Shorter time periods are viable were only interim storage or near future retrieval of the waste's constituents are anticipated or likely.

- Ideally, the design life should be equal to the period of noxiousness of the encapsulated waste. However, based on this criteria, an infinite design life would be required the isolate most radionuclides and many hazardous constituents, unless treated to eliminate there hazardous characteristics. A design life of up to 1000 years and beyond if technically practical, should be strived for when permanent disposal is a consideration.

- The encapsulation facility should be designed to remain stable over the selected design life, and not allow for the environmental dispersal of the waste in the event of extreme natural events, including the maximum credible earthquake and the probable maximum precipitation and flood events.

- The cover should be designed to reduce water infiltration to the waste to 1.0 E-7 cm/sec or less using natural materials. Greater infiltration rates can only be accepted by demonstrating compliance with acceptable dose/risk criteria.

- The encapsulated facility should be designed to deter and impede human, animal, and plant intrusion into the facility, and to minimize maintenance requirements.

- Analytical and numerical modeling of the design should be performed, using site-specific parameters, to demonstrate that health/risk based performance criteria will be met in the long-term (over the design life time), identify short term performance monitoring needs, and to select parameters for the design of individual disposal cell components.

- Community involvement and acceptance are desired for the selection and implementation of the waste disposal method selected.

INTERNATIONAL APPROACH TO TECHNICAL AND ENGINEERING DESIGN DETAILS

The case histories presented generally span the universe of waste disposal options, and include stabilization in place, waste exhumation and stabilization on the remediated waste site in a new, engineered disposal cell, and waste exhumation and relocation for disposal off of the remediated site. The decision as to stabilization in place, stabilization on site, or disposal off site was made, in each case, on the basis of socioeconomic considerations and site suitability. Based on these case studies , the following international norms are suggested for selecting one or the other of these stabilization and disposal options:

- Stabilization in Place

  Acceptable if the site is <u>not</u> over an active fault or a major potable aquifer, and the disposal cell cannot be designed to withstand the Probable Maximum Flood which may impact the site area.

Foundation soil should have sufficient natural geochemical properties or the groundwater regime must be remote enough to indefinitely prevent adverse impact on groundwater quality accessible to human and environmental receptors. Groundwater impacts, for a particular stabilization design, may be quantified by demonstrating compliance with either stipulated groundwater concentration standards, or acceptable dose/risk criteria for reasonable maximum exposed receptors through environmental media pathway modeling and analysis.

- Stabilization On Site

  Acceptable if all or part of the site meets the criteria for Stabilization In Place. This option would be used if uncertainties in the waste characteristics were such that an over conservative In Place cell design would be required to mitigate the lack of specific knowledge of the geotechnical and geochemical properties of the waste source term. For these situations, exhumation of the waste would be justified to characterize it, and, perhaps, treat the waste and place it in an engineered encapsulation disposal cell with or without a liner.

- Disposal Off Site

  Acceptable if the site is not conducive to In Place or On Site Stabilization. Although economic considerations must be considered in the waste encapsulation scheme finally adopted for implementation, the selection of this option would be balanced against the availability of a suitable and much more stabile site in the vicinity of the remediated site, and the assurance that waste transport does not involve unacceptable risks to receptors located in neighborhoods through which the material is moved.

While the details of each of the disposal options described above differ, they all should involve the following technical approaches that constitute acceptable international engineering norms:

- Use natural materials such as soil and rock; do not rely, in the long term, on geosynthetic materials.

- Provide at least one and preferably two components to fulfill each functional requirement. Multiple redundancy of function is preferred.

- Select only the most durable rock available; if durable rock is not available, provide adequate thicknesses of soil to fulfill the same function.

- Use conservative design assumptions, techniques, and analytical modeling approaches, and provide components and design features to mitigate the potential consequences of the worst case scenarios.

If a new disposal facility is built at a new site for radioactive and hazardous waste, the site selection should be such that a basal cell liner system is not required. The natural foundation soils should be adequate to protect groundwater quality in the long term through geochemical attenuation or dilution.

If a new cell is built at an existing site, the installation of a basal liner with leachate collection system may be warranted to provide an additional component for enhanced groundwater protection, and to readily obtain regulatory and public acceptance of the new cell on the site. The appropriate site has been selected, if cell performance analyses can demonstrate there is no negative groundwater impact even if (and when) the basal liner system fails.

CONCLUSIONS AND RECOMMENDATIONS

In this paper an array of disposal cells and covers for the encapsulation of radioactive and hazardous wastes from site remediation have been described. An attempt has been made to show that the specific regulatory requirements covering the waste management do not generally circumscribe the waste encapsulation design. Universally acceptable disposal cell designs can be developed and implemented using international norms which isolate the waste for the long-term, hinder intrusion into the waste by humans, animals and plants; prevent inadvertent dispersal by wind and surface water erosion, control the infiltration of water, limit radon flux, and limit distress and damage of the cell by extreme natural forces. The number and specific characteristics of the layers used in the disposal cell design may be determined by modeling of the cell performance relative to compliance requirements and regulatory objectives.

The primary factors that dictate the design of the cover for radioactive and hazardous waste must be the nature of the site; the characteristics of the waste; the availability of suitable construction materials; and above all the need to protect human health and the environment for as long as practical and possible. In translating these desiderata into the real world of design criteria and technical and engineering approaches, a set of necessary and appropriate norms is postulated for any and all radioactive and hazardous waste disposal cells. If adopted, it is believed that continual technical and economically practical encapsulation of radioactive and hazardous wastes from site remediation activities will be possible.

RELEVANT REFERENCES

The following reference material provides additional insight and information on the design and implementation of disposal cells and covers for long-term encapsulation of radioactive and hazardous wastes.

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