Isolation of abandoned uranium tailings

Isolement de stériles miniers d'uranium abandonnés

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SYNOPSIS The radioactivity in tailings from processing of uranium ores can enter the environment in two forms: 1) Radon gas, the product of decay of uranium and radium; 2) Water-born contaminants, carried into the ground-water by leaching. A typical approach to controlling the escape of radon is to provide a cover of compacted moist soil. This cover can also help in the control of leaching, though total isolation using a compacted soil underliner may be required.

This paper discusses the radiological and chemical aspects of tailings isolation, including the following key aspects of design of an isolation system: (1) Reduction of the rate of radon exhalation (radon flux) by specifying a computed thickness of cover, 2) analysis and control of leaching and contaminant migration, 3) design of riprap for cover protection, and 4) certification of long-term durability of the cover protection material.

INTRODUCTION

Uranium tailings are produced when uranium ore is crushed and subjected to extraction processes, including acid leaching, ion exchange, precipitation, etc. The products resulting from these separation processes are uranium, which is of course the useful product, and tailings, which are discarded. A typical uranium tailings deposit is shown in Figure 1. Even though most of the uranium is removed from the ore, the extraction processes do not capture 100 percent, and the amounts left in the tailings are enough to make them radioactive to a level requiring special consideration.

Modern tailings management techniques include careful isolation, which minimizes the threat to humans and the environment. However, tailings deposits, formed before the dangers to people were fully realized, were often not so rigorously controlled. The steps needed to isolate tailings deposited under these conditions are the subject of this paper.

The health threat from uranium tailings is generally not the direct radiation, which is minor, but the gas, radon, which is given off as the uranium, and other radioactive elements present, decay. The radon not only gives off radiation at a harmful rate, but can be inhaled into the lungs, where it can decay into lead and remain in the body in this form until death. In addition, leaching of radioactive elements out of the tailings into the ground water can cause migration of these elements offsite, resulting in exhalation of radon at other locations.

Non-radioactive metals (lead, nickel, copper, arsenic, etc.) are often present in the tailings at toxic levels, posing an additional threat to the ground water. Finally the sealed site must be made secure against breaching, erosion or disturbance by human, animal or natural forces, which might accelerate radon emission, leaching, or actual transport of tailings to offsite locations.

Figure 1. Typical Abandoned Uranium Tailings Deposit (Photo provided by DOE UMTRA Project Office, Albuquerque)

The basic unit of radiation is the curie, Ci, defined as 3.7×10^{10} disintegrations per second. This unit appears in uranium tailings studies in the following three ways:

1. The concentration of radioactivity in radon in a given volume of the atmosphere is given in curies (or more commonly picocuries) per liter. (One picocurie = 1 pCi = 10^{-9} curies.)

2. The rate at which radon leaves a unit area of tailings surface (radon flux) is given in picocuries per square meter per second (pCi/m^2/sec).

3. The concentration of a given radioactive element (radium, thorium, or uranium) in a unit mass of tailings is given in picocuries per gram (pCi/gm.).

The radiological and chemical standards to be met in isolation of uranium tailings in the United States were developed by the Environmental Protection Agency (EPA, 1983). Two alternative sets of standards are acceptable to EPA:

1. Remove all material contaminated to concentration levels exceeding 5 picocuries per gram (pCi/gm) in the top 15 cm of soil and exceeding 15 pCi/gm for any 15 cm thickness at greater depths. This brings the site to a condition allowing unlimited public access; or

2. Seal the site in a manner satisfying the following requirements. (In this case, except for maintenance activities, the site must be secured to prevent future access.)

   a. Average concentrations of radon at the site boundary do not exceed 0.5 pCi/l, or average radon flux from the site surface does not exceed 20 pCi/m^2/sec.

   b. Ground-water aquifers are protected or restored to a level determined on a case-by-case basis taking into account relevant State and Federal Water Quality Criteria, considerations described in EPA's hazardous waste management system (47 FR 32274, July 26, 1982), feasibility, cost, and the future value of the aquifers.

The elapsed time for uranium, radium, etc., to decay to safe levels of radioactivity exceeds 10,000 years. Because the practicality of designing structures to last one thousand years can be questioned, EPA standards stipulate a minmum design life of 200 years and, where practical, a design life of 1,000 years (EPA, 1983).

PREDICTION AND CONTROL OF RADON FLUX

Measurement of the distribution of radioactive materials in an abandoned tailings deposit is illustrated by the work of Baker, et. al. (1984), at the Canonsburg, Pennsylvania site. (See Mason and Ball, 1984, for overview of this work.) At Canonsburg, surface gamma-ray exposure rate measurements were obtained (giving radon flux rates), surface soil samples were taken and analyzed (giving concentrations of radioactive contaminants), and borings were drilled and logged (giving gamma-ray exposure rates with depth). Radioactive material at varying concentrations, ranging as high as 1,000 pCi/gm, was found to be distributed heterogeneously throughout the site.

It was determined that a practical approach to tailings isolation would be to collect material having contamination concentrations exceeding 100 pCi/gm in a single location, minimizing the area requiring the thickest seal. (U.S. Department of Energy, 1983). Before receiving the tailings the area would be lined with clay to form the bottom of an encapsulation cell and to restrict leaching. Therefore, contour maps showing the thickness of material exceeding 100 pCi/gm were prepared for use in planning the excavation and designing the encapsulation cell (Fig. 2).

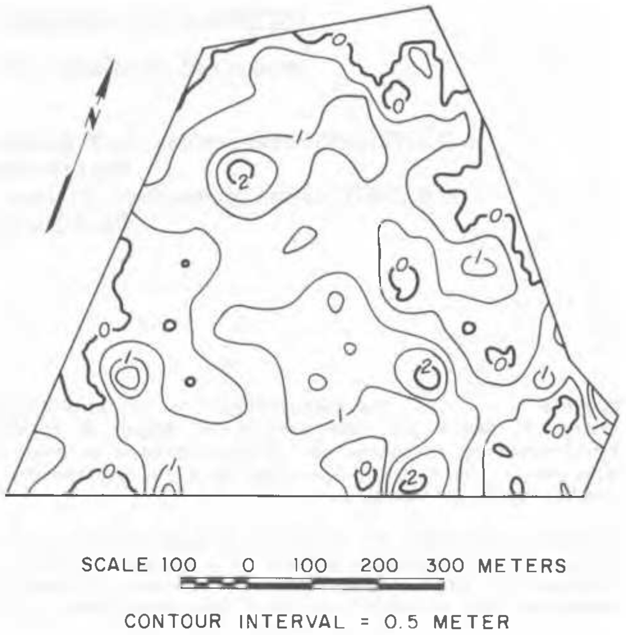

Figure 2. Thickness Contours for Typical Deposit of Contaminated Material - Radiation Level 100 pCi/gm (After Baker, et. al, 1984)

Figure 2, showing the irregularity of distribution of the contaminated material, was used to estimate the volume of material to be excavated. Contour maps showing the elevation of the lower boundary of the material contaminated to levels exceeding 100 pCi/gm, were also prepared to define the limits of required excavation.

Control of radon flux from tailings is generally achieved by providing a cover of compacted moist soil, which becomes the radon barrier. The resulting reduction in flux depends on the thickness of the soil cover and the residual moisture content of the soil, expressed in terms of degree of saturation. The flux can be estimated using a procedure developed by Rogers and Nielson (1981), which is used by the designer to determine the soil layer thickness required to avoid exceedence of the allowable limit of 20 pCi/m^2/sec. The soil layer is protected from erosion and desiccation by overlying layers of riprap and vegetated topsoil. The residual moisture content for a given design will depend on the corresponding long-term water balance. A typical cover cross-section is shown in Figure 3.

PREDICTION AND CONTROL OF GROUND-WATER CONTAMINATION

Even tightly compacted clay will have a permeability coefficient greater than zero, so that for significant rates of precipitation, infiltration through the radon barrier can occur. The rate of precipitation, infiltration through the radon barrier, and through the radon barrier into the tailings, can be predicted using the computer program HELP developed by Walski, et. al. (undated). This program, Hydrologic Evaluation of Landfill Performance, models the effects of monthly precipitation on a layered system, accounting for the permeability and slope of each layer. The program

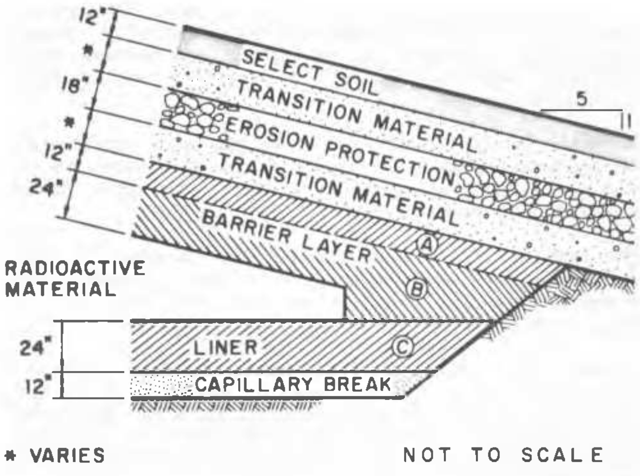

Figure 3. Cross-Section for Typical Encapsulation Cell (After Thiers, et. al., 1984)

predicts runoff at the upper surface of each layer, infiltration into and through each layer, and evapotranspiration. Based on an assumed permeability of 10^{-7} cm/sec., infiltration through the radon barrier at Canonsburg will be at the rate of 1.2 inches per year, for the local annual rainfall of 38 inches/year. (U.S.D.O.E., 1983.)

A low permeability liner placed between the tailings and the underlying soil restricts upward inflow from any temporary rise in ground-water level. (The tailings should be located above the long-term ground-water level.) The liner is designed to permit seepage of precipitation infiltration through the tailings and lining without ponding.

The change in ground-water level expected as a result of installation of an isolation system can be predicted using the Illinois State Water Survey finite difference hydrodynamic flow mode (Prickett and Lonnquist, 1971). Contaminant travel from tailings to the water table has been modeled by Gilbert, et. al. (1983). Studies have shown that the time required for uranium at Canonsburg to be leached from the tailings to the water table may be as much as 2,000 years (Brinkman, 1983).

Lateral migration of contaminants within the ground water can be predicted using the Prakash (1982) equations. In the ideal design, the concentration in the ground water is diluted to acceptable levels before exiting the site. (This is the case at the Canonsburg site, Brinkman, 1984.) If necessary, the soil cover thickness can be increased, or the soil permeability decreased by adding bentonite, to conform to water quality requirements.

SIZING OF RIPRAP TO PREVENT RILL GROWTH IN A LAYERED SYSTEM

A schematic cross-section of a typical tailings pile cover is shown in Figure 3. The design storm for the 1000-year life is generally taken to be the probable maximum precipitation-PMP (U.S. Nuclear Regulatory Commission, 1983). The resulting runoff will form rills in topsoil which may extend downwards to the underlying riprap. In one approach (Bone and Schruben, 1983), rill spacing and the resulting drainage area contributing to a given rill are determined using rill patterns observed by Mosley (U.S. Nuclear Regulatory Commission , 1983). A typical rill pattern is shown in Figure 4.

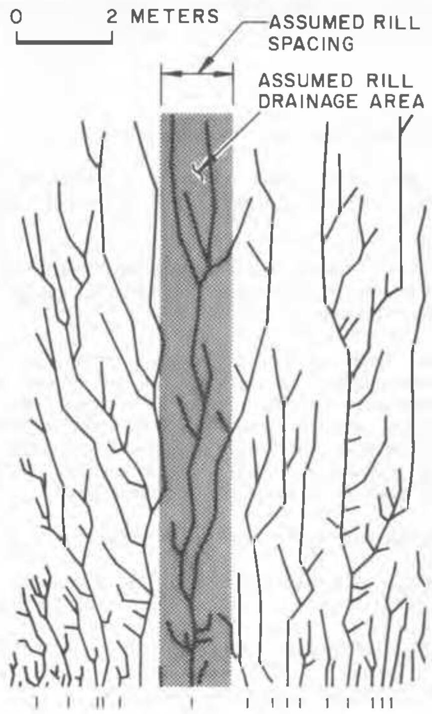

Figure 4. Typical Rill Development on Plane Surface (After USNRC, 1983)

Applying the design storm to the drainage area contributing to a given rill, it is possible to compute the peak flow to be carried by the rill. It is then assumed that a trapezoidal rill cross-section will be formed, with the bottom width equal to two times D_{50}, the mean size of the riprap. The rock size to prevent further down-cutting can then be determined using methods presented by the U.S. Department of Transportation (1975). D_{50} values of 10 to 12 inches were required at Canonsburg, which has a relatively high rainfall and a 5H to 1V cover slope (Bone and Schruben, 1983).

CERTIFICATION OF ROCK DURABILITY FOR 1,000-YEAR DESIGN LIFE

Prediction of riprap durability for a design life of 200 years using testing procedures currently available (hardness, sulfate soundness, freeze-thaw, etc.) is not possible (Lindsey, et. al., 1982). Until predictions using present test methods become more reliable, it will be necessary to use historical data as the primary evidence of durability for protection of uranium tailings covers. In this approach, fresh surfaces of a rock in question that have been exposed for long periods of time are examined for signs of weathering, and data obtained in this fashion form the main basis for certification.

For example, in the Canonsburg, Pennsylvania area, rock from a particular formation has served in building foundations and as paving stone for periods of approximately 100 years. The weathering during this period has been negligible, forming at the most a 1/32-inch thick layer of discoloration, with no change in stone size. Based on the available evidence, this formation has been designated an approved source of riprap for encapsulation cell protection at Canonsburg.

SUMMARY

Uranium tailings pose two threats:

1. Radon gas, given off as the radioactive constituents decay, can enter human lungs and cause radiation damage.

2. Radioactive elements and other heavy metals can be leached into the ground-water, producing toxic effects locally and off-site.

Contaminated material can be removed from the tailings site or encapsulated in an envelope of compacted moist soil. Encapsulation will meet EPA requirements by reducing radon concentrations at the site boundary and radon flux from the site surface, and controlling contaminant migration to the ground water. Encapsulation design must consider four key aspects:

1. Prediction and control of radon flux.

2. Prediction and control of ground-water contamination.

3. Protection of the radon barrier.

4. Certification of long-term design.

Radon flux is the rate at which radon is given off at the surface of the tailings deposit. Procedures for predicting this rate are discussed. It can be controlled by covering the tailings with compacted moist soil. The same procedures can be used to design the soil cover.

Contaminants can be leached to the ground water by downward seepage of infiltration, lateral seepage of ground water, or a rise and fall of ground water. The compacted soil cover can control infiltration; separating the tailings and the ground water can be accomplished by relocating the tailings, lowering the ground-water table, or extending the soil cover around and below the tailings, forming a soil envelope.

The soil cover, which forms a radon barrier, must be protected from erosion. This is currently accomplished using riprap, covered by topsoil. Design of riprap to resist the probable maximum precipitation is discussed. Isolation systems for uranium tailings are to be designed for a 1,000-year life if practical, with a minimum design life of 200 years. Given the reliability of available testing procedures for prediction of riprap durability, the use of the historical data approach is recommended for certification of riprap for a 200-year life.

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