Uranium Mill Tailings Covers: Evaluating Long-Term Performance

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Abstract: The U.S. Department of Energy (DOE) applies three tools to project the long-term performance of engineered covers for uranium mill tailings: monitoring, modeling, and natural analog studies. Field demonstrations and monitoring using lysimetry and soil water sensors, although expensive, provide direct measures of performance and are used to test the credibility of models. Numerical models engender an understanding of the complexity of environmental processes acting on engineered covers and can be used to link performance with risk. Natural analog studies help identify and evaluate likely changes in cover environments that cannot be captured by relatively short-term monitoring and modeling. Natural analog studies have been particularly useful for understanding possible long-term influences of climate change, ecological change, and pedogenesis on the performance of engineered covers. Analogs of local responses to climate change exist as proxy ecological and archaeological records of similar paleoclimates. Influences of ecological change are inferred from the ecophysiology of plant communities representing successional chronosequences. Pedogenic effects are inferred from the physical and hydraulic properties of soil profiles considered to represent future states of engineered covers. This paper presents examples of performance monitoring and natural analog studies conducted in support of the long-term stewardship of uranium mill tailings sites.

The Long-Term Surveillance and Maintenance (LTSM) Program managed by the U.S. Department of Energy Grand Junction Office provides stewardship services for DOE sites across the country (*www.doegjpo.com/programs/ltsm/*), including disposal cells designed and constructed in compliance with the Uranium Mill Tailings Radiation Control Act (UMTRCA). The regulatory standard for longevity of these designs is 1,000 years. One of the LTSM Program's responsibilities is to evaluate how changes in the environmental setting, both short-term and long-term changes, may alter the performance of UMTRCA disposal cells (DOE, 2001). The LTSM Program also collaborates with the following agencies on cover monitoring and long-term performance studies:

- Federal Facilities Program, U.S. Environmental Protection Agency (EPA) Region 8.
- Alternative Cover Assessment Program (ACAP), EPA National Risk Management Research Laboratory.
- Subsurface Contaminant Focus Area (SCFA), Office of Science and Technology, U.S. Department of Energy.

LTSM Program Cover Performance Studies

The design philosophy for UMTRCA cover systems evolved in response to regulatory changes and applications of lessons learned (Bergman et al. 2000). Before groundwater quality standards were promulgated, the design process focused on radon attenuation and the 1,000-year longevity standard. The early designs consisted basically of three layers: (1) a compacted soil layer (CSL) or radon barrier overlying the tailings, (2) a rock riprap layer at the surface, and (3) and a layer of coarse sand sandwiched between the CSL and the riprap layer.

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The LTSM Program has evaluated the hydrologic performance of some early designs. For example, the Program evaluated the effects of plant root intrusion on the saturated hydraulic conductivity of the CSL at the Burrell, Pennsylvania, disposal cell (Waugh et al. 1999). Within 3 years after construction, a diverse plant community had established in the rock cover. Within 10 years, Japanese knotweed had rooted through the rock layer and the underlying 90-cm CSL. Air-entry permeameters (Stephens et al. 1988) were used to measure the in situ saturated hydraulic conductivity (K_{sat}) of the CSL. The K_{sat} averaged 3.0×10^{-5} cm/s at locations where Japanese knotweed roots penetrated the CSL compared to 2.9×10^{-7} cm/s at locations with no plants. The weighted-average K_{sat} for the 6-acre cover, calculated using the leaf area index for Japanese knotweed, was 4.4×10^{-6} cm/s. At a nearby reference area with a subsoil consisting of the same type of clay, the K_{sat} averaged 1.3×10^{-4} cm/s. Earthworm holes, root channels, and soil structural planes all contributed to macropore flow of water. The reference area was considered to be a reasonable analog of a possible long-term condition of the Burrell CSL. However, performance models show that because of the low levels and mobility of contaminants, the consequences of root intrusion will not increase risks to human health and the environment.

USEPA Region 8 Caisson Lysimeters

The LTSM Program and the EPA Region 8 are conducting a lysimeter study of the engineered cover constructed for the uranium mill tailings disposal cell at the Monticello, Utah, Superfund site. The cover is a modified RCRA Subtitle C design that combines fundamental ecological principles with the required engineered barriers (Berwick et al. 2000). Ground-water recharge is limited naturally at Monticello where thick loess soils store precipitation until evapotranspiration seasonally returns it to the atmosphere, thereby maintaining unsaturated conditions in the subsoil. The cover design mimics and enhances this natural water balance. A capillary barrier underlying a thick soil “sponge” enhances water storage and limits downward unsaturated flow. Two drainage lysimeters were constructed to monitor the soil water balance for the range of conditions in the actual cover. The lysimeters consist of corrugated steel caissons, 3.05 m in diameter by 2.75 m deep, that are lined with 40-mil HDPE. Each lysimeter contains three water content reflectometers and two thermocouples at eight depths, a tipping bucket gauge for drainage, and root observations tubes placed at four depths within the cover profile. Soil water content, soil temperature, and meteorological data are monitored hourly. The cover layer sequence was constructed inside the caissons to match as-built engineering parameters for the actual cover. Instrumentation is accessed through a central caisson measuring 1.52 m in diameter and 3.66 m deep.

USEPA ACAP Cover Performance Monitoring

The LTSM Program teamed with the EPA Alternative Cover Assessment Program to create a 3-ha drainage lysimeter in a facet of the 14-ha disposal cell cover at the Monticello Superfund site (USEPA 2000). Precipitation, drainage, runoff, and change in water storage are measured directly; actual evapotranspiration is estimated by difference. Any drainage from the capillary barrier within the lysimeter cover section flows down slope along a buried HDPE geomembrane, through a boot and pipe at the most downgradient edge, and into a vault positioned down slope from the collection area. Drainage volume in the vault is measured first by a tipping bucket and then by a dosing siphon. Surface runoff from a 10-m by 20-m area is diverted to a water collection basin similar to that used for drainage. Changes in soil water storage are monitored with water content reflectometers. Soil moisture potential and soil temperature are determined with heat dissipation units. A weather station monitors wind speed and direction, air temperature, solar radiation, relative humidity, and precipitation. Potential evapotranspiration is estimated by calculation of the energy budget using the field parameters of wind speed, relative humidity, solar radiation, and air temperature. Plant community measurements include species composition, abundance, and seasonality of growth.

DOE SCFA Natural Analog Studies

The common design approach for engineered covers implicitly assumes that long-term performance can be captured with model extrapolations of the results of short-term field tests. The LTSM Program has determined that uranium mill tailings covers have already changed in ways that could not have been predicted with numerical models. The LTSM Program and SCFA are collaborating on natural analog studies to discern reasonable ranges of possible long-term changes in the environmental setting of engineered covers. Natural and archeological analogs exist for ecological change, pedogenesis (soil development), and climate change (Waugh et al. 1994). Effects of ecological change are inferred by measuring water balance parameters in plant communities representing chronosequences of responses to climate shifts and secondary disturbances (e.g., fire). Pedogenic effects are inferred from measurements of key physical and hydraulic soil properties in natural and archaeological soil profiles that are considered analogous to future states of engineered soils. Analogs of local responses to future global climate change exist as proxy ecological records of similar paleoclimates. For example, a preliminary analysis of paleoclimate evidence in the Monticello area yielded average annual temperature and precipitation ranges of 2 to 10 °C and 80 to 60 cm, corresponding to late glacial and mid-Holocene periods (Waugh and Petersen 1995). This range of paleoclimate states is considered to be a reasonable first approximation of possible future climate conditions for input to cover performance evaluations. Current average annual Monticello temperature and precipitation are 8 °C and 38 cm.

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