A THICK HOMOGENEOUS VEGETATED COVER DESIGN PROVES COST- AND SCHEDULE-EFFECTIVE FOR THE RECLAMATION OF URANIUM MILL SITES NEAR SPOKANE, WASHINGTON

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Abstract

The Washington State Department of Health (WDOH) has licensed two medium sized uranium mills with tailings impoundments covering 28 and 40 hectares (70 and 100 acres), respectively. The uranium mill licensees have submitted closure and reclamation plans to the state, and site-specific conditions have determined the closure design features.

Conventional uranium mill cover designs usually incorporate an overall cap of one to three meters, which includes a low-permeability clay barrier layer. A technical evaluation of several uranium mill facilities that used this design was published in the fall of 1994 and reported that unexpected vegetation root damage had occurred in the low-permeability clay (or bentonite amended) barrier layers. The technical report suggested that the low-permeability design feature at some sites could be compromised within a very short time and the regulatory goal of 1,000 years performance might not be achieved. In October 1994, WDOH sponsored a technical forum meeting to consider design alternatives to address these reliability concerns. Representatives from the federal government, nuclear industry, licensees, engineering firms, and state regulatory agencies attended the workshop.

Risk factors considered in the evaluation of the uranium mill reclamation plans include: (1) radon gas emanation through the cover (the air pathway), and (2) migration of hazardous and/or radioactive constituents (the groundwater pathway). Additional design considerations include site structural stability, longevity of 1,000 years, and no active (ongoing) maintenance.

Both closure plan designs originally presented to the department incorporated conventional low-permeability clay or bentonite amended cover layer designs. The department determined that the low-permeability layers at the Washington sites would be prone to failure due to biointrusion and freeze-thaw at these sites. A thick homogeneous vegetated cover design was then evaluated. Consequently, both closure plan designs were revised. All outstanding design and construction regulatory requirements were addressed prior to final approval by the state. The revised plan meets regulatory requirements, allows for construction efficiency (cost and schedule), and meets QA/QC goals.

I. Introduction

The Waste Management Section of the Division of Radiation Protection in the state's Department of Health manages the Uranium Mill program through rules and regulations. These rules are the result of professional rule development based on legislative authority and evaluation of risk. The NRC[1] and EPA[2] each produced environmental impact statements as the basis for their uranium mill regulations. The state of Washington, as an NRC Agreement State, enforces the federal regulations under state legislative mandate[3] and agency rule.[4] The resulting rule language is presented in the form of performance-based, non-prescriptive "Criteria." The NRC has developed several guidance documents, with the most applicable being a Staff Technical Position for Design of Erosion Protection Covers for Uranium Mill Tailings Sites.[5] This paper describes the state's involvement in the evolution of the thick homogeneous vegetated cover design.

II. Conventional Cover Design

When the state's uranium mill licensees decided to terminate their radioactive materials licenses and begin closure and reclamation of their sites, the department required that final closure plans be submitted for approval. This review was a technical evaluation to ensure compliance with regulatory criteria. WDOH regulations allow licensees to propose any cover designs that can demonstrate compliance with performance-based requirements in the regulatory "Criteria". In 1994, both uranium mill licensees submitted closure plans[6] & [7] to the department for review and approval.

During the same period of time, a technical report[8] was published by the Uranium Mill Tailings Remedial Action (UMTRA) Project. The report described how biointrusion on rock-covered disposal cells had impacted the stability of covers at completed U.S. Department of Energy (DOE) sites. The study suggested that "continued plant growth on the rock-covered cells will alter the characteristics of the cover system. As roots advance through the cover, they introduce organic matter into the cover, and upon their death leave conduits through which liquids and gasses may pass readily. These roots and associated processes will eventually transform the radon barrier into a biological soil, which could degrade the performance of the engineered layer relative to its intended function." In response to this report and staff concerns, the Waste Management Section sponsored a technical meeting[9] to discuss and identify potential impacts to the low-permeability barriers from biointrusion, freeze-thaw, no active maintenance, and other factors.

III. Long-Term Reliability Concerns

One of the major concern with uranium mill cover designs is that they should be stable for 1,000 years. Studies show that conventional cover designs may not meet this longevity requirement. Since department regulations do not allow the inclusion of active maintenance into closure plans, cover designs must be evaluated to account for this. The following paragraphs describe typical problems faced by uranium mill sites, which conventional cover designs may not be adequate to meet:

III.1 Background

Uranium production in this nation supports the uranium fuel cycle for the nuclear power industry, and the nation's nuclear weapons program. Uranium mill tailings are the byproduct (waste stream) resulting from the production of uranium oxide from uranium ores. Tailings are produced as a result of chemical separations and typically produce an acidic liquid slurry waste stream. The high volume liquid waste is pumped to large impoundments where pH balance is accomplished and solids precipitate and settle out. Larger particles settle near the discharge, with fine particles settling further away. This results in a concentrating effect in the distribution of fine particles, sometimes called "slimes." These slimes are difficult to stabilize because they do not readily de-water and lack structural strength.

The radioactive constituents of potential environmental concern include radium-226 and radon-222 gas produced by radioactive decay. Radon gas has a half-life of 3.8 days and diffuses from the tailings through the cover to the atmosphere. Uranium mill covers are designed to slow the rate of radon gas diffusion/emanation to acceptable regulatory standards. Many of the radioactive and hazardous constituents present in the tailings may affect the groundwater. Their mobility and potential impacts are dependent on many factors. For example, the site-specific geology and hydrogeology can strongly influence how well the uranium mill tailings are isolated. Design features of the impoundment include the liner (or lack thereof), methods used to control pH during waste disposal, ore and process variables, and cover design. Environmental site features of major importance include weather, upstream watershed characteristics, soil characteristics, earthquake potential, and natural vegetation succession.

Since radium-226 has a half life of 1620 years, the regulatory requirement for the isolation of uranium mill tailings is "1,000 years to the extent reasonably achievable, and, in any case, for at least two hundred years." From a regulatory point of view, it is impractical to expect that active, ongoing maintenance could be assured by administrative and institutional controls for more than 100 years. Therefore, the regulatory requirement states that "final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation."

III.2 UMTRA Project Experience

Burt and Cox reported on experiences at UMTRA Project sites in a technical report published in 1994[8]. The six sites discussed included five in relatively dry locations, some at higher elevations, and one in much wetter Pennsylvania. In each case, site-specific environmental and design features affected the impact and rate of sand and vegetation intrusion. The contaminated materials at these disposal cells were covered by a three-part system consisting of a radon barrier, a bedding layer, and a rock erosion layer. The radon barrier consists of a highly compacted soil/clay layer designed to limit radon emanation and water infiltration. The bedding layer is designed to support the rock erosion layer, prevent the rock from penetrating the radon barrier, and reduce or prevent the erosion of the radon barrier. The rock cover is designed to prevent water and wind erosion from affecting the stability of the disposal cell. In the relatively short time-span of one to three years after construction completion, the characteristics of vegetation coverage had exceeded design expectations. Deep-rooted species had invaded cover areas and had begun to grow into the radon barrier. Maintenance of the sites now includes cutting of vegetation and use of herbicides. Report recommendations include design modifications for new sites to either increase cover rock thickness to prevent vegetation, or increase thickness of cover to minimize detrimental effects of deep-rooted vegetation.

Conventional cover designs are typically based on a design infiltration rate of 2.5×10^{-7} cm/sec (1.0×10^{-7} in/sec), and there are concerns that vegetation or animal intrusion could increase the infiltration rate.

III.3 Biointrusion

In 1994, the department began its technical review of the submitted closure plans, with both plans incorporating relatively thin (about two meters) cover designs with low-permeability clay or bentonite amended soil layers. The amended layers were 0.5 to 1.0 meter (1.5 to 3 feet) thick and were placed below native soil and a top soil cover. A rock mulch and synthetic layer were included in one of the designs. After extensive study, the department determined that biointrusion could cause failure of the low-permeability clay barrier. Factors which influenced this determination included the inability of clay-type soils to self-heal following root intrusion, and the ability of burrowing animals to move through supportive soils to depths of two meters, thus creating holes (voids) or channels which then could fill with less permeable materials. The net effect of such biointrusion is possible failure of the low-permeability clay barriers during the 1,000 year period at these sites.

III.4 Freeze-Thaw

For many sites at higher elevations or in northern latitudes, the soil column will freeze to an appreciable depth during periods of prolonged cold weather. This is true for each of Washington's sites, which are located in the northeastern section of the state. Soil columns in these areas are known to freeze to a depth of one meter or more. When considering a design that must retain performance for such a long time period, even rare occurrences that affect performance must be considered. It has been demonstrated that highly compacted clay barriers lose their low-permeability performance after repeated cycles of freeze-thaw conditions. Therefore, any clay barrier designed in a soil horizon susceptible to freeze-thaw action will not likely retain its long-term low-permeability performance.

III.5 Maintenance

Any design that must last 1,000 years must not be based on administrative/institutional controls to assure performance. Man's historical record does not justify such an allowance, even in the best of assumptions of political and economic stability. If maintenance is required over short time periods, then such a design cannot be considered, unless there is no other practical approach. When the department considered this factor, it became obvious that plant and animal intrusion would occur at Washington's sites because there is sufficient moisture and the soil and weather conditions are favorable for plant and animal life. The department had to assume that biointrusion would occur; not only that, but biointrusion could potentially be very beneficial to the cover design. Therefore, the cover must be designed to either prevent biointrusion, or to incorporate it; either way, ongoing active maintenance would not be required.

IV. Thick Homogeneous Vegetated Cover Design

The concept of a thick homogeneous vegetated cover design is certainly not new and novel in the sense that it has been considered in the past. Such a design is simple and is not considered high-technology. It is simply a brute force method that uses a larger mass of material (greater thickness) to provide isolation of tailings. The larger mass is more stable, considering structural impacts from the environment (erosion, earthquakes, root penetration, etc.). The larger mass is also less sensitive to construction methods and techniques, material properties for available borrow soils, and requires less exported materials (bentonite, clay, rock, synthetics, etc.).

IV.1 Vegetation

The thick cover design must account for vegetation and animal intrusion. Since the presence of vegetation is almost guaranteed, one should consider its effects on the design. A thick cover that contains homogeneous, free-flowing material will be self-healing and the presence of plant root successional effects will not provide preferential pathways, since a low-permeability barrier layer is not present. Performance will not be degraded by the presence of plants and plant roots. If the cover is thick enough, a very large portion of root mass will be found in the upper portion, and root effects will be diminished. A cover depth of four to five meters is considered sufficient to mitigate biointrusion impacts.

There is a very significant benefit from vegetation in that plants transpire large volumes of water from the ground into the air in the process of producing plant mass. The ratio of water volume transpired to plant mass produced is species-dependent, and ranges from 100 to 1,000. Evapotranspiration is greater during higher temperature summer conditions and generally exceeds natural rainfall precipitation, on average. Since most precipitation occurs during winter and most evapotranspiration occurs during summer, the soil column (cover) must be thick enough to contain the water without allowing deep percolation during the winter and spring, and release it in the summer and fall through evapotranspiration. If the cover is thick enough, the seasonal cycles will not impact deeper than the upper layer of the cover, and the tailings will remain well protected. In fact, if vegetation is deep rooted enough to access available moisture, essentially all of the year's accumulated precipitation will be removed by the end of the dry season. This process achieves the same general result as a low-permeability clay layer design.

IV.2 Radon Gas Emanation

Radon gas emanation is a process of vapor diffusion through the soil and release to the atmosphere at the surface, where it could be inhaled. The radon gas inhaled could decay and produce a negative health effect to the exposed person. In practice, a relatively thin (about one meter) low-permeability clay barrier layer incorporated into a conventional design (total cover thickness of about two meters) has almost the same theoretical radon emanation rate as a thick (about four meters) homogeneous uncompacted soil cover. With conservative assumptions of soil characteristics, soil moisture, and soil compaction, it becomes quite unlikely that any external variable can cause the thick soil cover design to exceed the design limit. This is not the case with thin barriers placed near the surface. For instance, gas diffusion is highly dependent upon soil moisture content. A thick cover design is much more likely to maintain generally average soil moisture properties during the course of seasons and years than will a thin clay layer.

IV.3 Infiltration of Radioactive or Hazardous Constituents

Infiltration of moisture through the cover, and subsequent percolation through tailings and the underlying vadose zone to the groundwater, will determine the groundwater impact. This impact is generally in the form of a concentration (e.g., ppm) or a rate of contaminant flux, (e.g., gm/yr). For radioactivity, the usual units are pCi/l for concentration and pCi/yr for flux rate, and each radionuclide is considered individually because of the inherent difference in potential health effects. Reducing infiltration rates to zero theoretically eliminates the groundwater impact, since a potential waste stream that does not flow is not evident (impacting) to a potential recipient. Low-permeability barrier layers that are likely to fail their design permeability rates will likely produce greater infiltration rates on average over the design life of 1,000 years, than thick homogeneous vegetated cover designs that are optimized for vegetative production and high rates of evapotranspiration. Specific site conditions are important to this general statement and must be fully evaluated to achieve the benefit expressed.

IV.4 Structural Stability

The structural stability design parameters for uranium mills provide guidance to assess performance over the long term. This includes resistance to the detrimental effects of wind and water erosion, earthquakes, post-construction settlement, rock durability limitations, and others. The design analysis that justifies the design compliance with structural requirements includes long-term wind and water erosion and deposition estimates, and flooding from a probable maximum precipitation (PMP) event and its resulting probable maximum flood (PMF). In all cases, the thickness of the cover enhances compliance and long-term reliability performance. The effects of settlement can produce changes in slope that could affect erosion or deposition. Closure plans reviewed by the department used very shallow slopes (less than 2%) and did not require rock mulch on the surface to attain erosional stability. This enhances the natural vegetative production needed by other performance parameters. It was determined that even if settlement occurred and changed the slope, it would not be significant to erosional performance; vegetation would eliminate any ponding of water that might result, so there would be no increase in infiltration. The detrimental settlement effects of compacted clay barriers (infiltration breaks) are absent in thick homogeneous cover designs. Therefore, an uncompacted cover design would not be compromised by settlement. The department also found that the thick homogeneous cover is easy to build and readily meets design specifications.

IV.5 Longevity

The thick homogeneous cover was determined to be the most suitable for assuring compliance with the 1,000 year design criteria at Washington State sites.

IV.6 Administrative Requirements

The regulations impose several administrative requirements that take effect after construction is completed, and after the radioactive materials license is terminated. By regulation, the following requirements are imposed: (1) surety is provided, based on a 1% real rate of return, to perpetually fund a surveillance program; (2) the state or federal government will own the land and/or provide responsibility for long-term performance; and (3) the facility will be annually surveyed.

V. Conclusions

The performance-based regulations relative to the development of closure and reclamation plans at Washington's two uranium mill sites have allowed for a potential improvement in their closure designs. There is now another method of isolating waste using a thick cover approach that has potential long-term reliability benefits, when compared with the low-permeability, relatively thin barrier designs. It is likely that these benefits can also be achieved at other sites with similar environmental characteristics. In the following sections are examples of department experience at the two uranium mill sites, both of which are located in northeastern Washington:

V.1 Cost Impacts

The closure design for one of the mills was approved conceptually, on condition that detailed construction designs and specifications be submitted for review when the site is ready for final closure. It is estimated that by using the thick cover design instead of the conventional design, approximately $1 million will be saved on closure costs.

Closure of the other uranium mill is being performed in phases and contains a Tailings Reclamation Plan that includes the design basis and construction of the tailings cover and surrounding diversion channel. The mill building and process equipment were disposed of previously. Contaminated site soils were cleaned up in a separate plan that is essentially complete. Construction is well underway and is expected to be essentially complete by autumn 1996. The cover will be installed, the diversion channel cut, rock erosion protection placed, and exposed disturbed ground re-vegetated (seeded). Again, it is estimated that by using the thick cover design instead of the conventional design, approximately $1 million will be saved on closure costs.

V.2 Schedule Impacts

Schedule impacts at one uranium mill facility have not been identified, as the design is approved only conceptually and details of construction scheduling have not been developed. Nevertheless, it will certainly be a positive schedule benefit when bentonite imported from Wyoming and mixed and placed to tight specifications is replaced by native borrow material from the site or from other local sources.

It is readily apparent that the closure project at the other uranium mill facility would be greatly impacted by the schedule implications of a conventional cover design. The normal weather conditions in northeast Washington would make it quite difficult to produce a highly compacted clay barrier in any case. The normal requirement to monitor for settlement of the cover would, in itself, cause an additional year of construction. The design, as approved is approximately 25% complete at this time and is expected to be greater than 95% complete this fall. When time is money, this schedule benefit will surely result in additional unaccounted cost savings.

V.3 Quality Assurance

Although not mandated, it is important for a regulatory agency to be cost or schedule conscious; it is a public service to be considerate of such things, so long as the environment and the public are adequately protected by compliance with regulatory requirements. Quality assurance can therefore provide the check that all regulatory requirements have been, or will be, met. Compliance has been assured by considerable technical review by a multi-disciplinary review team of engineers, hydrogeologists, health physicists, licensing specialists, and others. The licensees, their engineering and technical consultants and their contractors have been most cooperative. Quality control will be provided by department field inspection.

V.4 Long-Term Reliability

One of the best ways to achieve long-term reliability is to develop something that is in harmony with its environment and also resistant to the erosional and depositional forces that may come to bear. Such stability must be assured for both the relentless forces of everyday environmental impacts and for the intensity of the unusual event (floods, earthquakes, droughts, and others).

References

1. "Final Generic Environmental Impact Statement on Uranium Milling, Project M-25," NUREG-0706, Office of Nuclear Material, Safety and Safeguards, U.S. Nuclear Regulatory Commission, September 1980.

2. "Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing (40 CFR 192)," EPA 520/1-83-008-1, Office of Radiation Programs, U.S. Environmental Protection Agency, September 1983.

3. "Mill Tailings - Licensing and Perpetual Care," Chapter 70.121, Revised Code of Washington.

4. "Radiation Protection - Uranium and/or Thorium Milling," Chapter 246-252, Washington Administrative Code.

5. "Final Staff Technical Position, Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites," U.S. Nuclear Regulatory Commission, August 1990.

6. "Closure Plan for Closure of the Dawn Mining Company Uranium Millsite Near Ford, Washington," prepared by Dawn Mining Company, Shepherd Miller, Inc., Western Radiation Consultants, Inc., Keystone Scientific, Inc. and VZM, May 1994, and revisions thereto.

7. "Sherwood Project, Tailing Reclamation Plan," Prepared for Western Nuclear, Inc., Prepared by Shepherd Miller, Inc., December 1994, and revisions thereto.

8. Burt, Charles J., and Cox, Steven W., "An Assessment of Plant Biointrusion on Six UMTRA Project Disposal Cells," UMTRA Project, Albuquerque, NM, 1994.

9. Technical Meeting, Sponsored by Waste Management Section, Division of Radiation Protection, Washington Department of Health, "Conceptual Cover Designs," September 29, 1994, Spokane, WA.

DISCUSSION

BELLAMY: Do you know any basis for the thousand-year criterion that you mentioned, because I don't?

BLACKLAW: The first basis is that it is in the regulations as a criterion, and is specifically noted there. I believe it comes from the development of regulations by NRC, which also came from a generic environmental impact statement where risks were evaluated. I am sure that it comes from the half-life of radium-226, 1600 years.

CHAIRMAN'S CONCLUSION

BELLAMY: It is clear that decontamination and decommissioning in the waste management area is an up and coming concern and that we are going to have to tackle it in the years to come. Additional discussion of Hanford will be presented tomorrow at the working luncheon. I encourage everybody to have further thoughts on the topic.