# GROUNDWATER PROTECTION AND RESTORATION AT URANIUM MILL TAILINGS DISPOSAL SITES

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**ABSTRACT:** The U.S. Environmental Protection Agency proposed new groundwater protection standards for disposal cells constructed by the U.S. Department of Energy on the Uranium Mill Tailings Remedial Action Project. This paper describes: the technology development program undertaken to respond to the proposed standards; the revised design of disposal cells that meet the standards; the approach to the assessment of the performance of the cell, and in particular the establishment of the water infiltration rate through the cover; and the definition of appropriate groundwater compliance strategies. The paper illustrates application of procedures with a case history.

## INTRODUCTION

In September 1987 the U.S. Environmental Protection Agency (EPA) proposed, and in late 1989 plans to finalize, new standards for the protection of groundwater at sites that are part of the U.S. Department of Energy's (DOE) Uranium Mill Tailings Remedial Action (UMTRA) Project. In order to comply with the proposed and final standards, the DOE undertook an extensive technology development program and established new approaches to the design and construction of disposal cells that protect the groundwater at disposal sites.

This paper briefly describes the results of the technology development program and the new approaches to disposal cell design and cell performance assessment. Approaches are illustrated by reference to case histories.

## THE GROUNDWATER PROTECTION STANDARDS

The EPA issued final standards for the UMTRA Project inactive tailings piles in January 1983 (40 CFR 192). In 1985 the Tenth Circuit Court of Appeals remanded the groundwater portion of the standards (40 CFR 192.20 (a) (2) and (3)), at which time the court directed the EPA to establish general standards. On September 24, 1987, the EPA published proposed revised groundwater standards for the UMTRA Project (EPA, 1987). The final standards are likely to be issued in late 1989. The final standards, at least as applicable to issues discussed in this paper, are unlikely to differ significantly from the proposed standards.

The EPA has incorporated into the proposed (and hence the final) UMTRA Project groundwater standards, technical requirements that parallel requirements of the Resource Conservation and Recovery Act (RCRA). These requirements include the concept of a single groundwater protection standard (40 CFR 264.92) that applies regardless of site-specific conditions; a list of hazardous constituents that are associated with the mill tailings or milling process (40 CFR 264.93); compliance levels for identified constituents, which can be either background concentrations, maximum concentration limits (MCLs) or alternate concentration limits (ACLs) (40 CFR 264.94); and a point of compliance (POC) (40 CFR 264.95).

In addition to establishing the options of defining ACLs, the proposed standards provide for invoking supplemental standards. Supplemental standards may be invoked (40 CFR 192.21) for one or more of the following reasons:

- o The remedial actions required to satisfy the otherwise prevailing standard would produce environmental harm that is clearly excessive compared to the health benefits (40 CFR 192.21(b)).
- o Restoration of contaminated groundwater is technically impracticable from an engineering perspective (40 CFR 192.21(f)).
- o The groundwater is a limited use aquifer; i.e., Class III (40 CFR 192.21(g)).

When invoking ACLs, the DOE must demonstrate that the remedial action reduces contaminant constituents to levels as low as reasonably achievable (ALARA). When invoking supplemental standards, the DOE must demonstrate that the remedial actions "come as close to meeting the otherwise applicable standards as is reasonable under the circumstances" (ACARUC) (40 CFR 192.22(a)). In either instance, the DOE must demonstrate that human health and the environment are protected (40 CFR 192.22(d)).

## TECHNOLOGY DEVELOPMENT PROGRAM

The results of the extensive DOE technology development program are described and summarized in DOE, 1989a, and a series of detailed reports on special topics including:

- o Alternative materials for low permeability covers.
- o The design of vegetated soil covers.
- o The use of geomembranes in waste disposal facilities with very long design lives (1,000 years).
- o The effect of freezing and thawing on the properties of fine-grained soil radon and infiltration barriers.
- o Erosion resistance of soil barriers.
- o Rock durability requirements for longevity.
- o Tailings treatment for source modification.
- o Evaluation of hydrogeochemical barriers to modify seepage quality.
- o Aquifer restoration characterization.

The results of all of these studies have been integrated into the new alternative disposal cell design approaches described in subsequent sections.

## DISPOSAL CELL DESIGN

When designing a disposal cell, we (1) examine alternative sideslope and topslope options; (2) select appropriate details; and (3) combine appropriate details that deal with site-specific needs into a complete cell design.

Figure 1 shows possible alternative disposal cell perimeter dike details. One or more of these may be selected, as required, for specific site constraints. Figure 2 shows a general cover that incorporates all of the design elements that may be used in an UMTRA Project disposal cell. Depending on site conditions, one or more of these elements or components may be omitted. Three specific covers that derive from the general cover are:

- o The Standard Cover: this incorporates a radon barrier, a drain, and erosion protection rock. This cover could be used on both sideslopes and topslopes.

- o The Double Drain Rock Cover: the components include a radon/infiltration barrier of compacted soil; a drain; a zone of random soil, the purpose of which is to increase the depth of cover to protect the infiltration barrier against freezing and thawing; a bedding layer; and erosion resistant rock. This cover can be used on both topslopes and sideslopes.

- o The Full Component Cover: this cover incorporates all of the elements or components of the general cover (see Figure 2). Because of the difficulty of providing for stability and preventing erosion, this cover is likely to be used only on the topslope of a disposal cell.

## EVALUATION OF COVER INFILTRATION

A significant determinant of the performance of a disposal cell is the design of, and the allowable moisture flux through, the cover. Infiltration through the cover ultimately translates into seepage of contaminated water from the base of the disposal cell. If the seepage rate or contaminated loading exceeds threshold values, compliance with the groundwater protection standards may not be possible. Therefore in establishing compliance of the disposal cell (as designed) with the EPA standards, it is necessary to specify the allowable water flux through the disposal cell cover.

Covers for UMTRA Project disposal cells can be designed and constructed with operative moisture flux rates that probably vary from $10^{-7}$ to $10^{-9}$ cm/s. Even for a given design, variations in materials, the performance of the individual cover components, site cover [illegible] impossible to establish a single point value of water flux or cover infiltration. In reality, [illegible] [illegible] Neither the DOE nor anybody else has technical data to support a proposed probability [illegible] [illegible] UMTRA Project (or any other waste disposal facility) cover. It is also probably not necessary as long as the assessment of the performance of the disposal cell considers the range of infiltration possibilities. In other words, the DOE should demonstrate that for [illegible]

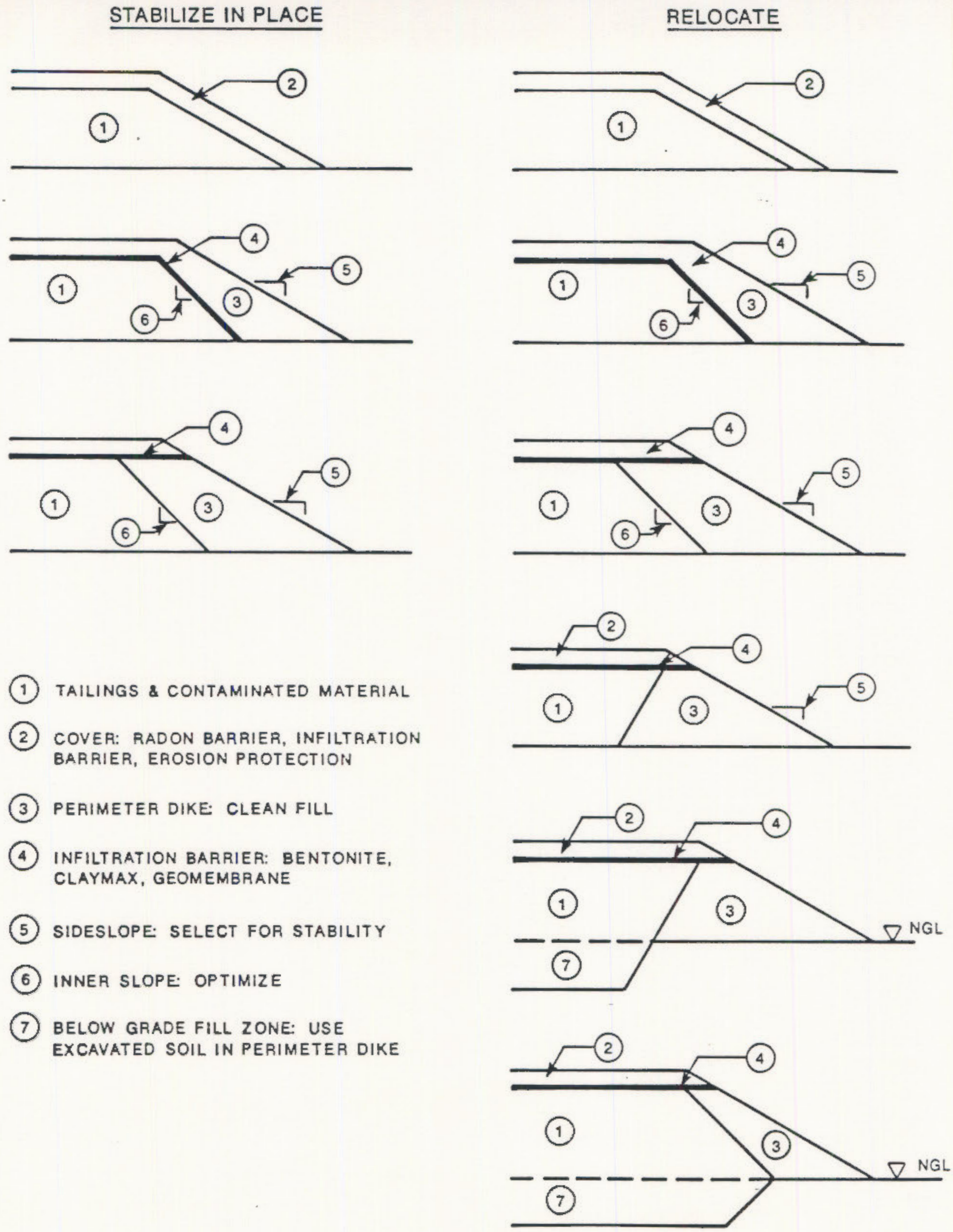


**FIGURE 1**
**"CHECKLIST"**
**PERIMETER DIKE ALTERNATIVES**

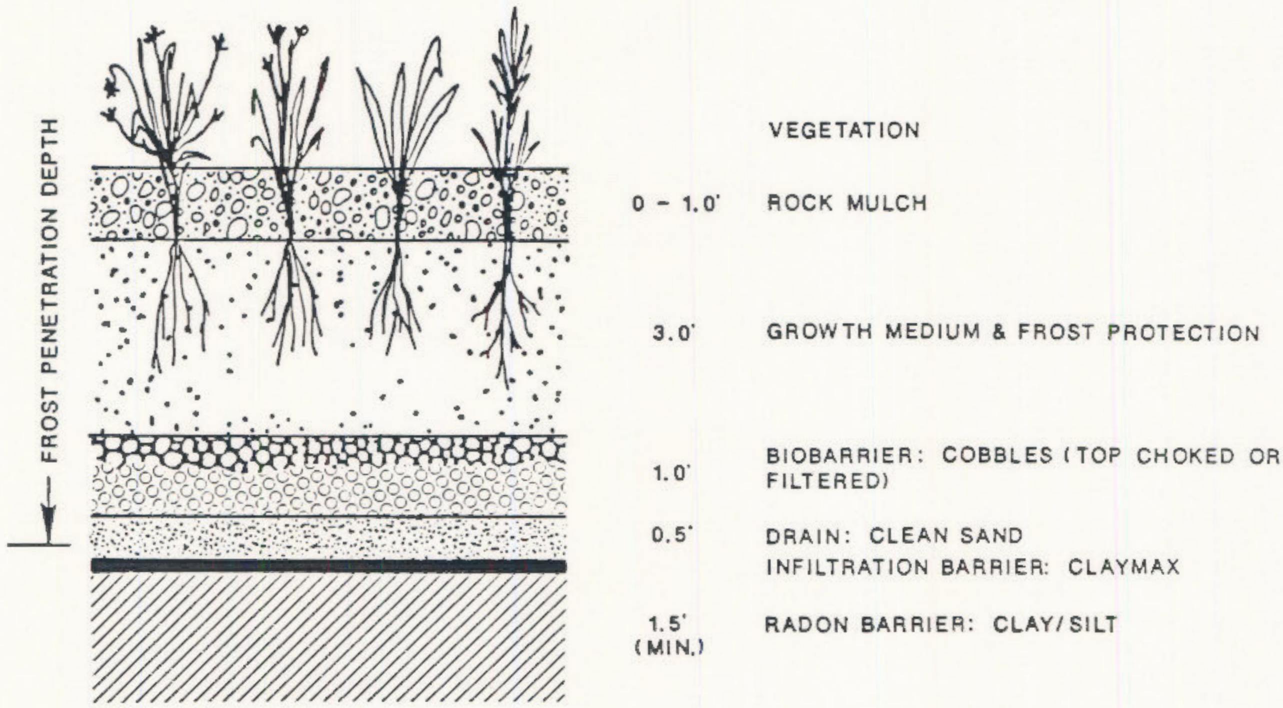


**FIGURE 2**
**"CHECKLIST"**
**TOP COVER**

the cell does not exceed background concentration, MCLs, or acceptable ACLs. Alternatively, the DOE may demonstrate that supplemental standards are applicable; therefore, groundwater standards compliance is not necessarily sensitive to cover infiltration.

In brief, then, to deal with inherent and inevitable uncertainties in the magnitude of the infiltration through the disposal cell cover, the DOE proposes to consider a range of reasonable infiltration rates, and show that one or more of the EPA's groundwater protection standards is achieved for the full, reasonable range of cover infiltration. This approach is considered consistent with the philosophy that underlies the following statement by the EPA, made in response to public comments on the proposed standards, and documented in the preamble to the draft final groundwater protection standards.

> "The EPA has decided not to delete the ACL provision because it is clearly needed if for no other reason than to deal with the possibility of unavoidable minor seepage over the extremely long design life (up to 1,000 years) of the disposal facility required by these standards. It is clear for controlled minor seepage next to disposal areas and when public use is not possible, that ACLs will usually be appropriate."

Table 1 lists the low, middle, and upper bound infiltration rate for the various possible UMTRA Project disposal cell sideslope and topslope covers.

In assessing the performance of a disposal cell and the resultant impact on the groundwater of contaminant seepage, groundwater impact evaluation is completed for the range of likely cover moisture flux rates. In designating the applicable groundwater compliance strategy, both the steady state and the transient drainage must be considered. Below we first discuss transient drainage, and then we discuss the identification of appropriate compliance strategies.

## LINERS

The proposed EPA groundwater standards require that relocated tailings placed wet of their "specific retention" be underlain by a "liner or equivalent." The understanding of the DOE is that the liner requirement is intended to deal with the situation that would arise if tailings were slurried for transport to a new site. As this is not planned, the liner requirement does not apply. In addition, the DOE does not consider it technically effective, prudent, or legally possible to place a liner beneath relocated tailings. The reasons for this opinion are that:

- o Geomembranes cannot be demonstrated to last for 1,000 years (the facility design life), and hence cannot be used.
- o A liner with a permeability less than the cover will cause the "bathtub" effect. (Drains to collect water are not maintenance-free, as required by the EPA standards.)
- o Low permeability natural soils will generally be of too low a strength to ensure embankment slope stability against the extreme seismic conditions for which cells are designed.

Liner equivalents may be taken to include hydrogeochemical barriers and buffer layers. The DOE has completed a detailed evaluation of the use of hydrogeochemical barriers.

**TABLE 1**
**COVER INFILTRATION RANGES**

| Cover Type | Infiltration (cm/s) | | |
|---|---|---|---|
| | Lower | Middle | Upper |
| Full Component | $2x10^{-9}$(a) | $5x10^{-9}$ | $10^{-8}$(b) |
| Standard | $10^{-9}$(c) | $10^{-8}$ | $10^{-7}$ |
| Double Drain | $10^{-8}$(d) | $5x10^{-8}$ | $10^{-7}$ |
| Clean Fill Dike | (e) | (e) | (e) |

NOTES:

(a) The measured hydraulic conductivity of Claymax[R].
(b) A reasonably achievable saturated radon barrier hydraulic conductivity.
(c) Or the unsaturated hydraulic conductivity of the infiltration barrier at a reasonable long-term average moisture content.
(d) Or the lowest achievable saturated hydraulic conductivity of the lowest permeability layer in the cover.
(e) Not specified, as infiltration does not contact the tailings.

The results suggest that hydrogeochemical modification of seepage from tailings by a distinct hydrogeochemical layer will require a relatively slow transit time for the seepage as it moves through the hydrogeochemical layer. Site-specific evaluations are required to evaluate the potential advantages of a hydrogeochemical layer for particular cases. Currently, no hydrogeochemical liner equivalent is planned for an UMTRA site, although some preliminary evaluations are planned for the Grand Junction, Colorado, site.

A standard design cover and a buffer layer were incorporated into the disposal cell at the Green River UMTRA Project site in Utah. The function of this buffer layer is to impede seepage for an extended period.

The groundwater compliance strategy for the Green River site involved demonstrating that contaminants from the tailings would not reach the underlying groundwater for a period equivalent to, or greater than, the design life of the cell. With this strategy, MCLs or background concentration of the identified hazardous constituents of the Green River site would be met at the point of compliance for the design life of the disposal cell. The layers of buffer material placed beneath the tailings included approximately eight meters of windblown "contaminated" materials and two meters of selected clean backfill material similar in texture to the windblown materials. The windblown materials were demonstrated to be relatively free of mobile hazardous elements by standard batch and column leach testing, and were therefore included in the analysis as buffering material beneath the tailings. Collectively, the windblown and buffer materials were demonstrated to retard the movements of contaminants to groundwater for a period estimated to be between 200 years (conservatively) and 1000 years (likely). Additionally, the tailings and underlying buffer materials were placed at very low moisture contents (seven percent and twelve percent volumetric, respectively) to ensure that transient drainage of tailings pore fluids would not invalidate the travel time compliance strategy. The upper moisture boundary (radon barrier) was compacted to a high density of 100 percent standard Proctor using six percent sodium bentonite; a saturated hydraulic conductivity of $2x10^{-8}$cm/s was measured in the laboratory on block samples taken from the filed.

## TRANSIENT DRAINAGE

Immediately after construction of the disposal cell, the tailings may be wetter than they will be in the future. With time, the excess moisture initially in the tailings will drain, and the long-term or equilibrium moisture conditions will be established. The equilibrium moisture content may be less than the initial moisture content. The period between the completion of construction and the establishment of equilibrium moisture content and steady state seepage conditions is considered to be the period of transient drainage. In high permeability sandy tailings, the period of transient drainage may be short because the drainage rate is high. In very low permeability tailings, the period of transient drainage may continue for many years. If the rate of transient drainage exceeds the steady state rate, the MCLs may be exceeded. As described in a subsequent section, when such a situation occurs, an appropriate groundwater compliance has to be adopted.

If a satisfactory groundwater compliance strategy for excess transient seepage is not possible, the tailings will have to be dried and placed at as dry a moisture content as possible.

Figure 3 shows the results of an evaluation of the effect of compacting tailings into place at different moisture contents on the transient drainage period and compliance achievement. As it is costly to dry tailings (about $0.20 per ton per percent of mass reduction of moisture content) it is theoretically most efficient and cost-effective to place

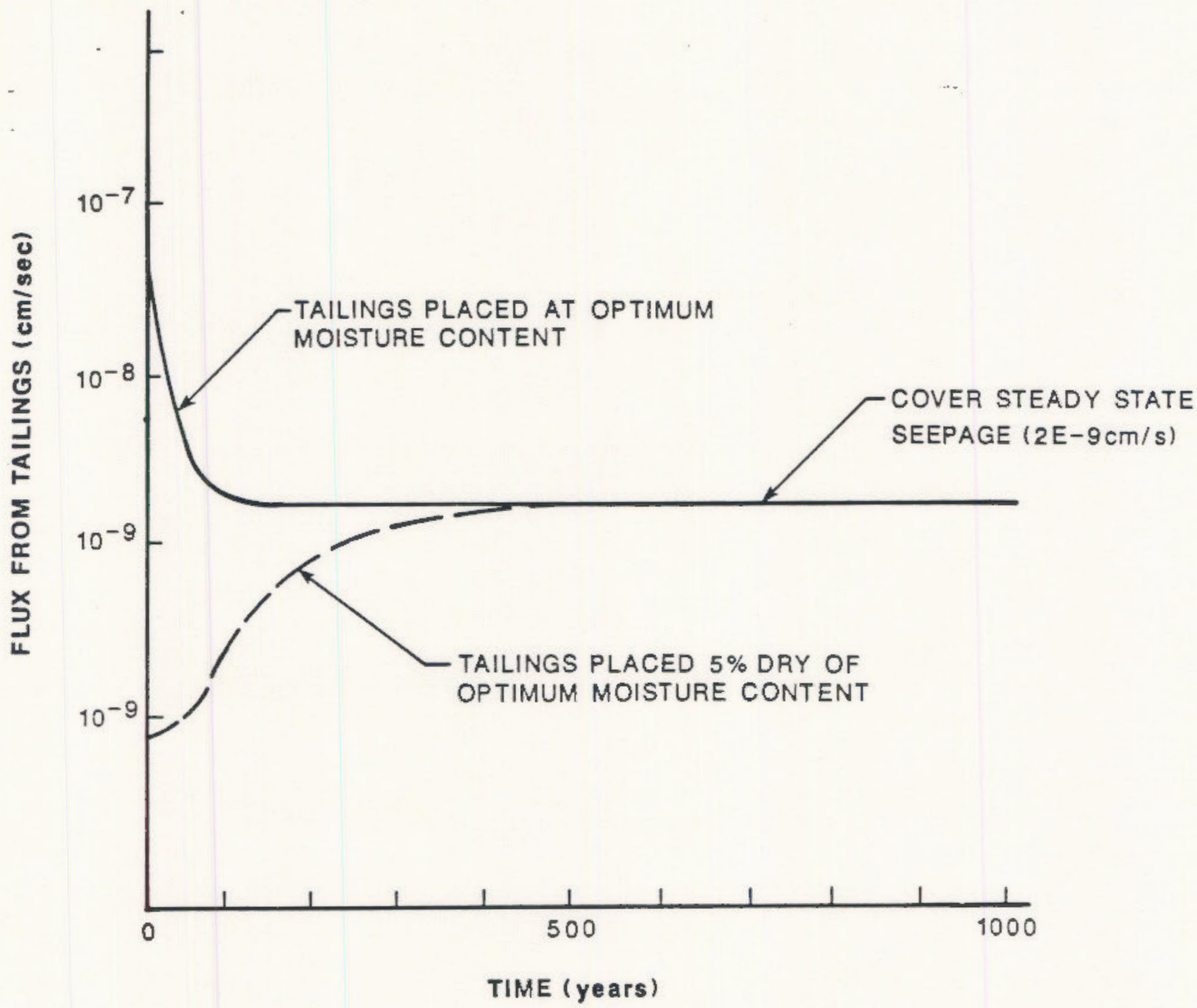


**FIGURE 3**
**TRANSIENT & STEADY STATE SEEPAGE FROM RELOCATED TAILINGS**

the tailings at the moisture content at which the transient seepage rate equals the long-term steady state seepage rate. In practice, it will be necessary to place the tailings a few percent drier than the most cost-effective moisture content, in order to account for the potential variability of the long-term cover infiltration rate, which is the main determinant of the steady state seepage rate.

At Green River, Utah, the sandy-textured tailings were compacted into place at between 10 and 12 percent drier than optimum (volumetric moisture content of seven percent). Compaction was controlled by the specification requirement to use four passes of a smooth drum vibratory compactor.

The tailings were compacted at about 93 percent of standard Proctor. Characteristic curves relating soil suction to moisture content indicate that at the placement density the unsaturated hydraulic conductivity of the tailings is near $2 \times 10^{-8}$ cm/s (at a volumetric moisture content of seven percent), which is the same as the allowed upper boundary flux of $2 \times 10^{-8}$ cm/s of the radon/infiltration barrier. As such, the Green River disposal cell was designed to operate as a unit, with the components of the cell (radon/infiltration barrier, tailings, and underlying compacted buffer materials) all placed at moisture contents commensurate with an unsaturated moisture flux of $2 \times 10^{-8}$ cm/s. By doing this, transient draining of tailings pore fluids did not invalidate the travel time groundwater compliance strategy for the Green River disposal cell.

## GROUNDWATER COMPLIANCE STRATEGY

If the transient drainage rate is always less than the steady state seepage, designation of the appropriate groundwater compliance strategy is in accordance with the scheme shown in Table 2.

If the transient seepage rate is likely to exceed the steady state seepage for less than 100 years, and the transient drainage will result in MCLs being exceeded, then institutional controls may be invoked to support ACLs for the period of transient drainage. If the transient drainage rate is greater than the steady state seepage, but MCLs are not exceeded, then MCLs are the applicable groundwater compliance strategy.

The approach to the designation of the appropriate groundwater compliance strategy outlined in this paper is open to criticism. Some of the criticisms and possible responses include:

- The standards are based on point values, not ranges, and envisage only one, not varying or uncertain compliance strategies. Response: This is true, but fails to account for the realities of the inherent variability of likely cover infiltration fluxes and the not-unreasonable request by the Nuclear Regulatory Commission (NRC) to consider the range of possible disposal cell performance.

- The definition of cover fluxes is arbitrary and artificial, and hence the compliance strategies are meaningless intellectual artifices. Response: The range of infiltration fluxes is indeed uncertain. It is simply not possible in the context of a program with a legislated end date (1994) to obtain the data that would be necessary to fully quantify flux ranges.

- Use of computer codes such as HELP, CREAMS, etc. predict very little, and in some cases zero, flux through UMTRA covers with vegetated soil

**TABLE 2**
STEADY STATE SEEPAGE GROUNDWATER COMPLIANCE STRATEGY DESIGNATION

| Groundwater Constituent Levels For Cover Flux | | | Groundwater Compliance Strategy |
|---|---|---|---|
| Upper | Middle | Lower | |
| <MCL | <MCL | <MCL | MCLs |
| >MCL | <MCL | <MCL | MCLs; identify ACLs as potential corrective action. |
| >MCL | >MCL | <MCL | MCLs; demonstrate that ACLs would be appropriate in the event of monitored MCL exceedance. |
| >MCL | >MCL | >MCL | ACLs |

surfaces. Why not simply accept zero as the basis for the groundwater compliance strategy, and avoid the intellectual sophistry associated with the proposed approach? Response: This objection ignores the fundamental conservatism inherent in regulators, the realities of nature, the limited predictive capacity of computer models, and the fact that field studies are available to show that computer models don't necessarily predict cover infiltration. To explain: The NRC has stated unequivocally that they believe the DOE will never be able to prove with the degree of assurance necessary for NRC concurrence that cover infiltration will be zero for 1,000 years. The NRC believes, as do the authors, that inherent variations in materials and natural forces make it prudent to evaluate a range of possible cover responses and performances.

- The approach, as described, provides only for a distribution of steady state cover flux, but ignores the distribution (or uncertainty) associated with: contaminant concentrations in the seepage and affected groundwater; the flow rate of groundwater; mixing modes and zones; and dilution and attenuation by foundation soils and rocks. Response: In theory and practice the distribution of all the noted parameters can be accounted for if such data are available. The end result of such an exercise would at most sites be identification of the need for ACLs either as a likely compliance strategy or as the preferred corrective action should an exceedance be monitored. On the UMTRA Project it is currently easier to define (by decree, as it were) cover flux variations than to define, measure, or quantify other parametric distributions. Hence definition of the distribution of all parameters has not been done to date, nor is this likely in the future; instead the approach described in this paper is proposed.

Too often laws and regulations are written without proper regard for the realities of nature. Laws may envisage certainty, whereas nature is random and therefore uncertain. The proposed EPA groundwater protection standards do not expressly acknowledge the possibility of the randomness of nature. Nevertheless, in providing for ACLs, monitoring, and corrective action, the standards do appear to offer regulatory avenues to deal with nature's variability. The issue is thus the way in which the disposal cell planner identifies, demonstrates, and promotes the site groundwater compliance strategy.

## GROUNDWATER REMEDIATION

President Reagan signed the UMTRA Amendments Act of 1988 into law on November 5, 1988. The law extends the Congressional deadline for cleanup of sites from 1990 to 1994. In addition, the Act authorizes the Secretary of the DOE to perform groundwater restoration activities in terms of the UMTRA Project "without limitation."

In pursuit of aquifer remediation, the DOE has defined possible groundwater compliance strategies at each UMTRA Project site and estimated the cost of the likely remedial work. Technologies being considered by the DOE include:

- Extraction of contaminated groundwater with wells or trenches.

- Treatment of contaminated groundwater prior to discharge, or reinjection into an aquifer by various methods including chemical treatment, biological treatment, and physical separation using evaporation ponds.

- o In situ treatment of contaminated groundwater using lixiviant injection or permeable treatment beds or wells.
- o Discharge of the contaminated groundwater following extraction, or extraction and treatment, by one of the following methods: discharge to surface water; infiltration; injection in shallow wells; injection in deep wells.
- o Employment of natural flushing as a passive restoration method.

Additional technical evaluations, discussion, and planning are required before site-specific remedial plans can or will be finalized.

The DOE has compiled preliminary cost estimates of compliance with Subpart B of the proposed standards. Depending on the details of the final EPA groundwater protection standards, as promulgated, the estimated cost could range from $300 million to one billion dollars, or about as much as the current UMTRA Project budget.

In accordance with its stated policy, the DOE will begin planning and implementing Subpart B compliance (groundwater restoration activities) once the final groundwater protection standards are promulgated by the EPA.

## CONCLUSIONS

EPA standards mandate an innovative and conservative approach to protecting the groundwater at disposal sites where inactive uranium mill tailings are stabilized.

As described in this paper, the DOE, in response to proposed new EPA groundwater protection standards, has:

- o Completed a series of special studies.
- o Compiled standard technical approaches to the assessment of tailings transient drainage rates.

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