AN EVALUATION OF GEOTECHNICAL AND HYDROLOGIC ASPECTS OF URANIUM MILL TAILINGS RECLAMATION IN THE USA AND CANADA

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ABSTRACT

Reclamation of inactive uranium mill tailings piles in the USA is currently in progress as part of a Federal remedial action program. Remedial work is done according to standards established by the Environmental Protection Agency (EPA). Implementing the standards involves relocating the piles, if necessary, to suitable sites, and covering them with a radon and infiltration control barrier and erosion resistant rock. A recent study in Canada defines appropriate approaches to stabilization in Canada of inactive uranium mill tailings piles. There are no legal standards governing such work in Canada. Generally the Canadian approach involves reduction of steep slopes, water control, sometimes a cover, and the establishment of a stable vegetation cover. Differences of approach in the two countries to remedial work reflect the differences in climate, population densities, vegetation, and the regulatory framework in each country. A recent evaluation of a less conservative approach to remedial action in the USA indicates that considerably increased probabilities of failure of the remedial works need to be accepted before a significant cost savings can be affected and therefore the conservative USA approach is generally reasonable and justifiable.

INTRODUCTION

Inactive uranium mill tailings piles in the USA are being reclaimed under the Uranium Mill Tailings Remedial Action (UMTRA) Project. In Canada, a review has recently been completed for the National Uranium Tailings Program on the design requirements for the long-term stabilization of Canadian uranium mill tailings impoundments. This paper describes the main criteria applicable to tailings pile remedial works (the USA term) or preparation for abandonment (the Canadian term), and hence details the differences in technical approach and effective life of the remedial works. These differences are explored by way of a description of the generic approach adopted in the USA, as part of the UMTRA Project, and a generic example of abandonment preparation in Canada.

USA TECHNICAL STANDARDS AND CRITERIA

The technical standards that govern remedial work at inactive uranium mill tailings piles in the USA were established by the EPA. The standards require that remedial work:

- o Be effective for up to 1000 years to the extent reasonably achievable, and, in any case, for at least 200 years.
- o Provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not exceed an average release rate of 20 picocuries per square meter per second (pCi/m^2s), or increase the annual average concentration of radon-222 in air or above any location outside the disposal site by more than one-half picocurie per liter.

In developing the standards, EPA determined "that a primary objective for control of the tailings should be isolation and stabilization to prevent their misuse by man and dispersal by natural forces such as wind, rain, and flood waters." Other objectives established by the EPA were to reduce radon emanations from the piles and to eliminate significant exposure to gamma radiation from tailings.

EPA determined that the potential for contamination of ground and surface water should be evaluated on a site-specific basis. In September, 1985, the US Tenth Circuit Court of Appeals set aside the EPA standard for ground water protection and directed the EPA to issue new regulations that are general and applicable to all sites. The DOE has proposed interim guidelines to EPA so that work on the UMTRA Project can continue. These guidelines are based on existing, applicable state and Federal standards.

The general technical approaches and methods and the design criteria adopted for UMTRA Project remedial action work are described in the Technical Approach Document (1). Caldwell et al. (2) provide a detailed discussion of this document. Table I lists some of the important technical requirements for design that are contained in the Technical Approach Document.

TABLE I

Some Pile Remedial Works Design Criteria

DESIGN PRECIPITATION AND FLOOD. All designs shall provide for the Probable Maximum Precipitation (PMP) and the Probable Maximum Flood (PMF); except in cases where it is clearly impractical for reasons of economics, unavailability of suitable materials, or technical impossibility, and then a lesser event may be evaluated.

SEISMIC DESIGN PARAMETERS. The design earthquake shall be that which causes the largest peak site acceleration or most severe effects at the site. The earthquake may result from rupture along an identified fault, or from an earthquake not associated with an identified feature but occurring no closer than 15 kilometers to the site.

RADON BARRIER MOISTURE CONTENT - RADON FLUX. To calculate radon flux through the pile, the design moisture content (which is the most critical parameter in such a determination) shall be that associated with a soil suction pressure of minus 15 bar suction. Thus, on an average pile, the design moisture content is about 7.5 to 15 percent.

RADON BARRIER MOISTURE CONTENT - INFILTRATION. No standards are set; however, in design the likely long-term upper bound moisture content is estimated by computer simulation of the likely processes of precipitation on the pile, the runoff from the pile, the short-term infiltration, and the effects of soil suction and evaporation in removing water from the radon barrier.

EROSION PROTECTION. The size of the rock required to prevent erosion in the event of flow from the PMP or PMF is determined with the Safety Factor Method (5) for slopes less than 10 percent, and with the method described by Stephenson (6) for slopes greater than 10 percent. These two methods have been shown in field trials to reasonably predict the performance of rock subjected to rapidly flowing water.

AQUIFER RESTORATION. Aquifer restoration has been proposed at many UMTRA Project sites. To date no restoration programs are planned, although evaluations are in progress for certain sites. In assessing the viability of aquifer restoration, the following are considered: effectiveness, cost, volume of contaminated water, removability of contaminants, the treatability of the water, and the availability of alternative water supplies.

CANADIAN URANIUM TAILINGS REVIEW PROGRAM

The National Uranium Tailings Program (NUTP) in Canada has recently completed a study (3, 4) which included:

- o A description of Canadian uranium tailings deposits and a review of long-term stability concerns relating to surface covers and radon gas releases.
- o A review and description of available technology for cover design and long-term stability evaluation.
- o Evaluation of the applicability of available technology to three generic Canadian uranium tailings structures.
- o Evaluation of alternative cover types which may be considered at the generic sites: this is done in order to identify suitable cover types and technology.

It is not the purpose of NUTP to define regulatory standards or requirements. This study, and others prepared under the program, examine current conditions at Canadian uranium mill tailings deposits, evaluate appropriate technologies, and attempt to define an acceptable approach to abandonment preparation and remedial works for long-term stabilization of Canadian uranium tailings deposits.

CANADIAN STANDARDS AND REGULATIONS

There are no laws or regulatory standards specific to uranium tailings pile remedial work in Canada. Deposits prepared for abandonment are subject to the regulatory control of the Atomic Energy Control Board, which has issued broad guidelines. The Board reviews abandonment plans on a case by case basis. In reviewing plans, the Board also considers appropriate Provincial and Federal regulations.

The NUTP study assumes that current design and construction technology should be able to achieve stable structures for 100 to 200 years and selected 1000 to 2000 years as the period for evaluation of the stability of abandoned deposits.

As regards the rate of release of contamination from the piles (analogous to the EPA requirement of 20 pCi/m^2s) the NUTP study approaches the matter on the basis that if the rates of change of release of contaminants from the piles are very, very small, then the changes in the release rates may not be significant for a very long time. Small but perpetual change which results in cumulative increases in release rates may bring about unacceptable rates of release in lesser periods. Rapid changes could result in catastrophic releases in short periods.

The NUTP study does not, however, define such critical terms as "very, very small," "significant," "very long time," or "unacceptable release rates." Such decisions are left to the companies and the professionals advising the companies affecting remedial works, regulatory authorities, and to the normal democracy of the public review and input process.

Some guidance may be obtained from the concept that remedial works should reduce releases to a level "as low as reasonably achievable (alara)." The rejection by the Tenth Circuit Court of the EPA site-specific approach to ground-water standards implicitly rejected the "alara" approach on the UMTRA Project, and hence probably on other similar programs in the USA.

Further, the NUTP study indicates that a cost benefit approach to deciding what is sufficient remedial action may be used or considered. This approach may be acceptable for ground-water protection on the UMTRA Project (as per the Tenth Circuit Court decision), but has specifically been rejected for the USA Superfund program.

IMPLEMENTATION OF THE UMTRA PROJECT STANDARDS

To date remedial work in terms of the UMTRA Project standards and criteria has been completed at two piles (Canonsburg, PA, and Shiprock, NM), is in progress at four (Lakeview, OR, Salt Lake City, UT, Tuba City, AZ, and Durango, CO) and is due to start within the next three years at the remainder of the 24 sites that are part of the UMTRA Project.

It is interesting to note that the piles occur in a diversity of climatic and political areas of the country. Conditions range from the wet areas of Pennsylvania to the desert climate of the Four Corners area in the southwest, from the heat of southern Texas to the arid plains of the Dakotas.

In general the following features are common in planning remedial work for the majority of the piles:

- o Site Locations: Piles may be stabilized in place or relocated. Concern for ground-water protection is the main technical reason for relocating piles. A second reason to relocate is the need to avoid floodplains and river meanders, or areas of population concentration.
- o Pile Shaping: Piles are shaped to promote drainage from the top and sides, to provide stable sideslopes, and to divert water around and away from the pile.
- o Radon Barrier: A layer of fine grained compacted soil is placed over the tailings to inhibit the infiltration of precipitation through to the tailings and to attenuate the flux of radon gas from the tailings.
- o Filter and Erosion Protection: In order to preclude erosion or piping of the radon barrier into the voids of the erosion rock, a layer of sand is placed over the radon barrier. Over that is placed a layer of durable rock of sufficient size to resist erosion by flow from the Probable Maximum Precipitation on the pile.

Detailed designs for the UMTRA Project are prepared in accordance with procedures described in the Design Procedures Document (7). Review of all designs by the Nuclear Regulatory Commission is done in terms of the NRC Standard Review Plan (8).

CANADIAN IMPLEMENTATION - GENERAL

The NUTP study evaluates the USA approach as described above and concludes as follows:

- o The climate, tailings, and sites at Canadian uranium tailings deposits are significantly different from those in the USA. While much of the USA technology is directly relevant to Canadian deposits, different emphases and different design techniques are required for Canadian conditions.
- o The environments of Canadian uranium tailings deposits are usually characterized by an abundance of good quality surface water with a low buffering or chemical attenuation capacity. This contrasts with the typically more arid environment of USA deposits which are often characterized by deeply weathered soils which have a high buffering or chemical attentuation capacity.
- o Saskatchewan uranium deposits are high grade - up to 14 percent uranium. They also have a high nickel and arsenic content. This leads to concerns distinctly different from those for tailings from low-grade Canadian and USA ores.
- o Acid generation is a primary concern at the large low-grade, pyrite uranium deposits of the Elliot Lake region of Ontario. Acid generation results in acidic surface-water drainage and seepage. For such tailings the design of cover and erosion protection features will be significantly affected by concern for control of acid drainage.
- o The higher average moisture content in Canadian soils reduces radon emanation and this, combined with the remote location of many of the sites, makes radon emanation reduction a less critical concern in the development of a design methodology and stringent standards. (As previously noted, no standards for acceptable radon emanation are provided. Also, no guidance is given for determination of what constitutes "critical concern." Determination is left to the appropriate controlling authorities.)
- o The climax vegetation at Canadian sites is forest. Forest cover is therefore potentially a realistic long-term stable regenerative cover.
- o Water cover is considered to be an acceptable cover in Canada, particularly where control of acid generation is required. Net precipitation and the ready availability of water are often such that this is a practical option.
- o Frost heave occurs at some Canadian sites, which can cause severe disruption of the tailings cover and hence an increase in the potential for tailings releases. This is particularly true in the uranium deposit areas of northern Saskatchewan.
- o Infiltration, to the extent that it contributes to seepage from the impoundment, is, as in the USA, a major concern in the design of a cover.
- o Rock waste covers increase infiltration and salt migration and do little to reduce radon emanation or prevent frost action. Where forest cover can be established for erosion protection, there appears to be little advantage in the use of rock covers. Rock waste or riprap, is, however, an essential part of cover design for gully erosion control.
- o The technology for the development of an economic cover that will support forest vegetation on uranium mill tailings is not adequately developed.

An extremely good example of the Canadian approach is described by Roberts and Filion (9). They performed a cost-benefit analysis of alternative closeout methods for a tailings impoundment in a remote location. They adopt the standard that radon emissions from the decommissioned pile should be as low as reasonably achievable. They calculate costs and public doses over 1000 years for minimum reclamation ($0.3 m, 10 man-Sv), in-situ pile reshaping and covering ($6 to 20 m, 4.3 man-Sv), and in-pit disposal ($64 to 97 m, 0 man-Sv). They show that for in-situ pile reshaping and covering, there is no significant reduction in public dose exposure in going from a concave fill covered pile ($6 m) to a convex erosion resistant and vegetation covered pile ($20 m). Hence they choose the former. The public protection provided by their scheme is similar to that resulting from typical UMTRA Project remedial works. A concave non-erosion resistant pile has not, to date, been accepted. The UMTRA Project considers this would not meet EPA standards. The NRC has licensed the American Nuclear Corporation Gas Hills pile in Wyoming for a cover of natural soil at a slope of ten to one; this cover probably provides similar erosion protection as anticipated at numerous Canadian piles.

CANADIAN IMPLEMENTATION - CASE HISTORY

Caldwell and Robertson (10) describe a case history of the implementation of the Canadian approach to uranium tailings pile stabilization. In brief the facility and the remedial works are as follows:

- The facility: Tailings deposited by wet discharge behind an embankment to cover an area of 75 hectares. Winters are long and cold, summers are short and cool. Mean annual temperature is minus 4.7 degrees C. Total annual precipitation is 402 mm and potential evaporation is 432 mm.
- The recommended remedial works:
  - Heavy rock riprap to control erosion of the embankment.
  - Reduction of embankment slopes and catchment areas.
  - Gravelly till and waste rock to control wind erosion of the tailings.
  - New filter drainage layer to augment potentially plugged drains.
  - Protection of surface water and control of discharge of contaminated water to the ground water by placing a thin soil cover; alternatively, place an infiltration barrier with an overlying drainage layer.

COMPARISON OF THE CANADIAN AND USA APPROACHES

The first and most significant difference between the Canadian and USA approaches to the reclamation of uranium tailings deposits is the absence of rigid or detailed standards and criteria for the works in Canada.

Second, because of the remoteness of many Canadian uranium mill tailings deposits and the typical higher soil moisture contents, radon emanation control is considered to be less critical. This reduces the perceived need for covers over tailings from low grade uranium deposits.

Third, in the areas of Canada susceptible to permafrost, frost heave and other frost effects may disrupt rigid covers. The use of flexible, self regenerating covers - such as those involving vegetation and water have long-term advantages in controlling erosion.

Fourth, the Canadian long-term stable cover choice is forest vegetation. At most USA sites vegetation cannot be relied on in the long term to provide a stable entity. In the USA, rock covers are almost exclusively relied on to provide erosion protection. Conceivably the Canadians will adopt a reasonably effective cover of deep soil in which forests may establish as their ultimate cover. Water cover is a practical and acceptable cover in appropriate circumstances in Canada.

In both countries rock riprap is accepted as the only viable way to control erosion where there is a potential for the development of significiant gullies.

In both countries a cover of low permeability soil is considered advantageous to control infiltration and inhibit radon emanation. In Canada the remote location of the tailings piles and the generally higher moisture content of the soils leads to acceptance of a lower control requirement for radon emanation than would be legally possible in the USA. Placement of a soil or rock cover is not necessarily mandatory in Canada.

There are often significant concerns for Canadian uranium mill tailings deposits and about other nonradioactive contaminants which might affect surface runoff and seepage. The main sources of such potential contamination are nickel and arsenic in some tailings, and acid generation in others. Considerable emphasis is therefore placed on the protection of the generally abundant surface-water resources.

In neither country is there an absolute standard for protection of the ground water. In both countries various groups, including government agencies, are moving to establish appropriate standards.

In the USA an active Federal program is in progress to complete remedial work at designated sites; in Canada the authorities are still defining the problem and considering potential solutions.

AN EXCURSION INTO THE PROBLEM OF LONGEVITY STANDARDS

Figure 1 shows an evaluation of potential savings for a group of sites in the USA for different longevity standards. The USA standards call only for stability for a defined period. They give little guidance to the designer as to the recurrence interval of the flood or earthquake for which he should design. As noted on the figure, the current USA approach is to accept an event with a very low probability of occurrence. This leads to adoption of the probable maximum event. The Canadian NUTP study accepts the use of probable maximum events, but may, in that it accepts "as low as reasonably achievable" and cost-benefit approaches, be able in its implementation to use recurrence interval events which lead to higher probabilities of failure. Indeed the NUTP study contains a detailed examination of the assessment of probability of failure by various failure mechanisms.

On the UMTRA Project it is generally accepted, on the basis of the cost savings shown on Fig. 1, that the decreased cost does not warrant accepting the commensurate increase in the chances of failure.

THE FUTURE

The 25 million tons of tailings at inactive uranium mill tailings piles in the USA is small by comparison with the 175 million and more tons of tailings in active piles. It is common cause that the cost of remedial work at active piles, if completed to the same standards as inactive piles, will be extremely high.

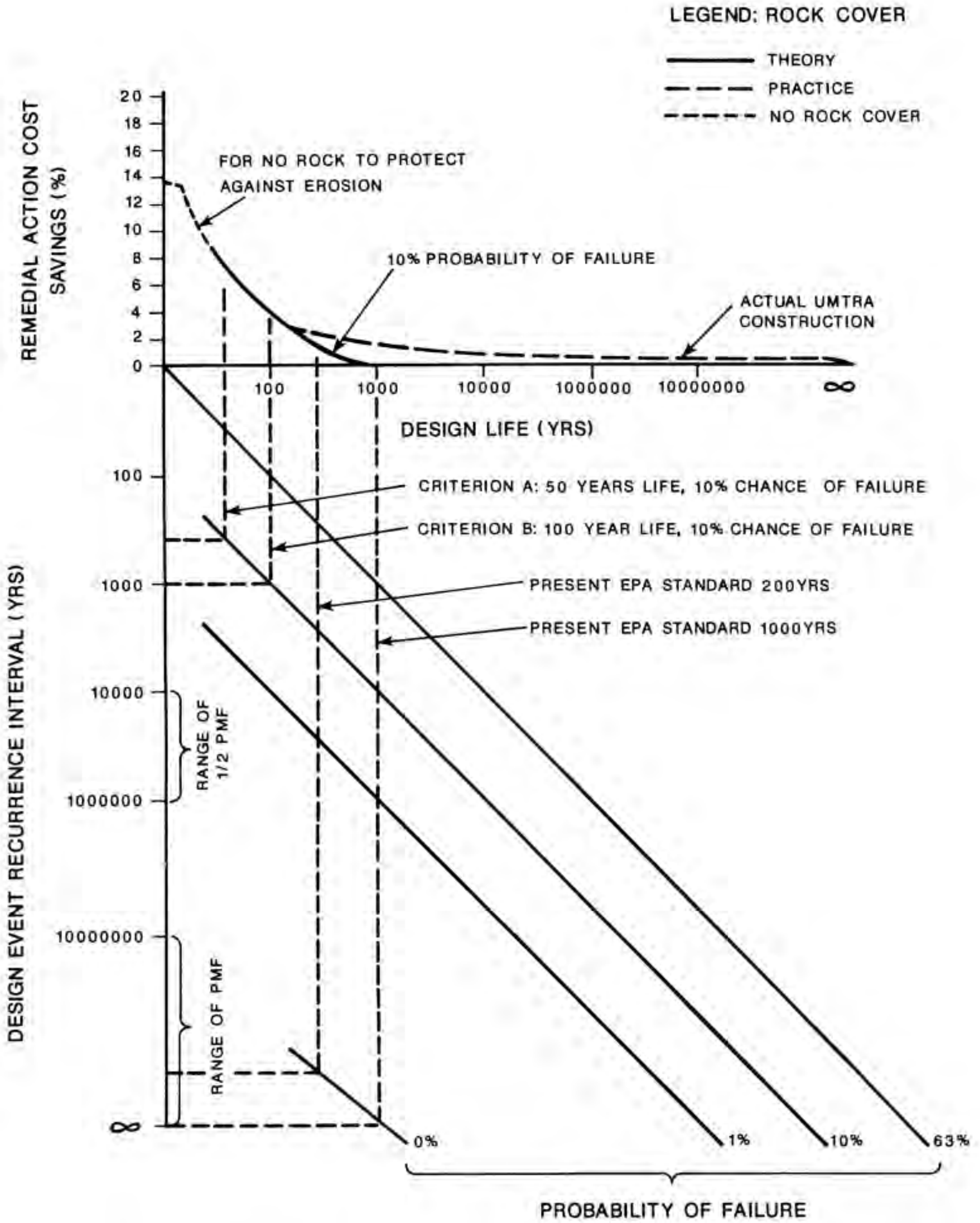

Fig. 1. Erosion Protection Cost Savings for Alternative Design Standards.

The question inevitably is asked: can we not adopt less stringent standards which still provide an acceptable level of health and environmental protection?

The most obvious reductions in the standards that will lead to a reduction of costs are those that relate to the remedial action design life, the permissible radon flux, and the need to provide maintenance free solutions. It may be argued that the Canadian approach should be the model for the USA active piles. In other words, instead of general stringent standards, site-specific standards should be adopted. Guidance on what is acceptable at a site would be based on the risk to human populations and the environment in the vicinity of the pile. The study by Roberts and Filion (9) is an example of an appropriate approach.

The success of the Canadian approach is essential if there is to be a reasonable chance of implementing a similar site-specific approach on active USA piles.

Evaluation of alternative approaches in the USA and Canada to those currently implemented on the UMTRA Project will have to, however, draw heavily on the practical experience and information built up on the UMTRA Project. For better or worse that project has set standards, formed attitudes, and shown what has to be done, what can be done, and how much it costs to do it. It will be necessary in evaluating alternative approaches, to build on the UMTRA Project, not ignore or avoid it.

If other approaches are to be evaluated in setting standards or risk management strategies for uranium mill tailings pile remedial action works, then an appropriate approach may be to evaluate the remedial action costs for a selected group of UMTRA Project sites for various alternatives:

- Design life requirements (say 50 and 100 years).
- Probabilities of failure during the 1000-year design life (say 10, 20, and 50 percent).
- Flux standards (say 50 or 100 pCi/m^2s).
- Maintenance requirements (say 50 percent of present value cost may be spent on future maintenance).
- Optimum cost/benefit solution.
- Defined maximum dose exposure to population within a given radius of the pile.

CONCLUSIONS

This paper has compared the approaches to the stabilization of inactive uranium mill tailings piles in Canada and the USA.

We conclude that the different climates and environments in the two countries lead to differences in the details of long-term solutions, although there are many similarities such as rock riprap to prevent severe erosion and a cover to control infiltration.

In the USA society has elected to act through the legal process of passing a Federal law, enacting and implementing a Federal program (at least for inactive sites), and setting specific standards. The issue has been debated and settled in the public forum, and is implemented in the light of intense public scrutiny. In Canada the issue is controlled by the responsible agencies working in cooperation with mining companies. There is a desire to avoid the rigidity and finality of Federal law, or the cost of Federal programs. Greater provision is made to rely and act on the advice of design professionals. It remains to be seen what the Canadian process produces.

Social, political, and legal differences in the two countries affect the nature and extent of the programs currently in progress to complete reclamation, preparation for abandonment, and remedial works. In both countries there is an awareness of the problem, a move to correct it, and a desire to move ahead.

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