RECLAMATION OF U.S. URANIUM MILLS EXTRAORDINARY REQUIREMENTS, EXTREME COSTS

by

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Abstract. The U.S. uranium mining and milling industry lasted less than 60 years, from the 1940s to the 1990s, but flourished for only about half that time. A total of 55 mills and heap leach facilities were operated, but only four are left in operation or on standby status as of 2000. The other mills have been, or are being, decommissioned and the sites reclaimed in accordance with federal standards under the Nuclear Regulatory Commission (NRC 1982a). Other federal agencies, states and Indian tribes regulate reclamation of uranium mines. Reclamation of uranium production facilities, including mills and heap leach operations but excluding in situ leaching operations, is based on the requirements of Appendix A of 10 CFR 40 as well as specific regulatory guides and standards promulgated by the NRC. These requirements are extraordinarily prescriptive and proscriptive and are extremely costly to satisfy. Uranium milling byproducts, including tailings and sludges, must be protected from release for 1000 years. The mill sites must be withdrawn from intentional use forever, preventing them from having any productive post-mining land use. Tailing impoundments must be covered so that the maximum rate of release of radon gas from the cover surface does not exceed 20 pCi/m^2/s. To meet these and other requirements, reclamation designs and construction practices had to be very conservative. The resulting costs are extremely high, averaging more than $50M for Uranium Mill Tailings Radiation Control Act Title I sites (reclaimed by the U.S. Dept. of Energy) and about $29M for Title II sites (reclaimed by the industry operators). Title II site reclamation has been achieved much more cost-effectively than Title I site reclamation, $4.19/lb. U_3O_8 produced versus $16.51/lb. U_3O_8, respectively. The experience of uranium mill reclamation shows that any reclamation measure intended to have a design life beyond the period of historical reference, 50 to 100 years, will have to include a substantial amount of conservatism to account for the time-related uncertainty. Such conservatism comes at very high costs.

Additional Key Words: NRC, tailings, UMTRA, UMTRCA

Introduction

The U.S. uranium industry has a unique history, in terms both of production and of reclamation. Uranium mining has been regulated under state rules similar or identical to those for other minerals, but the U.S. Nuclear Regulatory Commission (NRC) has regulated uranium milling.

Reclamation rules and regulation have also been split between state and federal jurisdiction, with states regulating reclamation of uranium mines and reclamation of uranium mills regulated by federal standards enforced either by the NRC or by individual states under agreements with the NRC. The federal standards for mill reclamation are focused on isolation of milling byproduct containing radioactive elements from the environment. The federal standards contain no concern about or requirement for post-reclamation

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land value or productivity – a reclaimed mill site is considered to be a containment vault with no other future use. Consequently, uranium mill reclamation standards require extraordinary measures to provide long-term isolation against any natural breach mechanism and to maintain institutional controls against human intrusion. These measures are extremely costly, setting uranium mill reclamation in a category by itself. This paper is based largely on research performed by International Nuclear Inc. (2000) for the U.S. Department of Energy's Energy Information Administration, in which the author participated. It describes standards, practices, and costs of uranium mill reclamation to allow the reader to draw comparisons to reclamation practices more familiar to him or her.

Historical Summary

The industry in the U.S. started around 1905 when uranium was first produced incidentally to radium and vanadium production, but uranium production for defense and energy applications was started in the 1940s by the federal government and subsequently turned over to private industry (Uranium Institute 1997). Prior to World War II, the U.S. had a modest radium and vanadium industry but no uranium industry separate from those two elements – uranium occurs with radium and vanadium but was little more than an associated mineral during that time.

When the Manhattan Project started to produce an atomic weapon in the early 1940s, uranium took on a unique and substantial value as a strategic element. With the advent of the Cold War and nuclear power generation starting in the 1950s, the uranium industry expanded rapidly. By the early 1980s, a total of 55 mills and heap leach facilities had been placed in operation, driven by prices that rose to over $40/lb of uranium ($U_3O_8$) by 1979. Then the accident at the Three-Mile Island nuclear power plant in Pennsylvania, overproduction, and unintended impacts of the Nuclear Waste Energy Policy Act of 1982, 42 USC Chap.108 (NRC, 1982b) prompted a rapid collapse of the industry, leading to the shutdown of most of the uranium mills by 1985 (International Nuclear Inc., 2000). By 1997 only five mills were left in operation, operable, or on standby (International Nuclear Inc., 2000; Uranium Institute, 1997). Total U.S. production from the 1940s through 1998 is illustrated in Figures 1 and 2.

In 1978 the U.S. Congress passed the Uranium Mill Tailings Radiation Control Act (UMTRCA) 42 USC Chap. 88 (DOE 1978). This law and subsequent amendments were enacted to ensure that uranium mill sites would be decommissioned and reclaimed sufficiently to protect the public against radiological hazards associated with uranium milling byproducts, specifically tailing solids and solutions containing radium and thorium as well as some residual uranium. The reclamation standards of UMTRCA as well as other related requirements of the Atomic Energy Act of 1954, 42 USC Chap. 23, as amended (NRC 1954), are implemented through 10 CFR 40, Domestic Licensing of Source Material (NRC 2000).

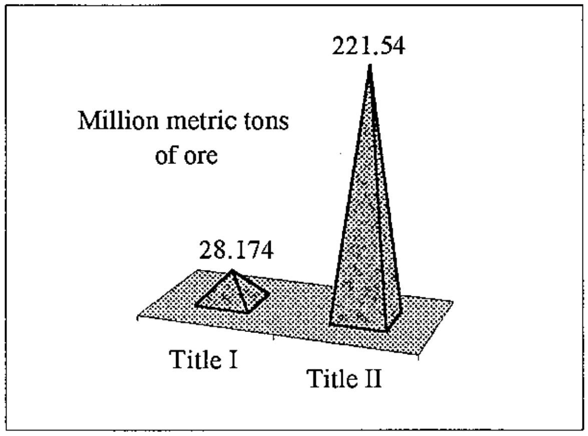

Figure 1. Total uranium ore processed by all mills. (International Nuclear Inc., 2000)

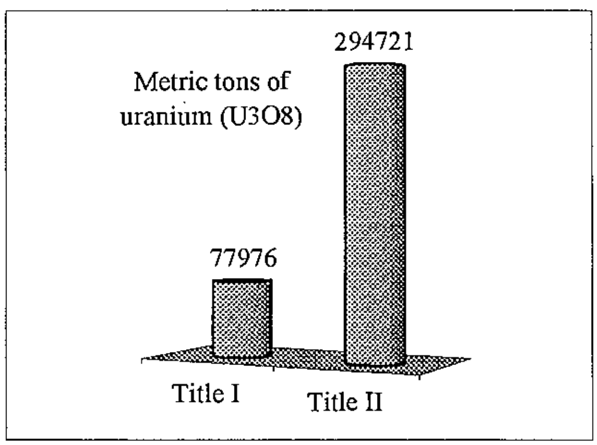

Figure 2. Total uranium oxide produced by all mills. (International Nuclear Inc., 2000)

The basis for all reclamation requirements is Appendix A of 10 CFR 40, entitled "Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content." Appendix A also includes reference to US

Environmental Protection Administration (EPA) standards in 40 CFR 192 (EPA 2000) for protection of ground water. Over the years since 1978, the NRC has gradually supplemented the 10 CFR 40 Appendix A requirements with a series of regulatory guides which have the effect of rules, and with technical guides and staff technical position papers that are not rules but in effect set benchmarks for NRC's acceptance of reclamation plans and practices.

Under UMTRCA, uranium mills are divided into two categories, described under Title I and Title II of the act. The Uranium Mill Tailings Remedial Action (UMTRA) Program was established to implement the Title I part of UMTRCA that was federal responsibility. Title I mills are those that operated up to 1967 and closed before passage of UMTRCA; their owners are not held responsible for reclamation, and the U.S. Department of Energy (DOE) is responsible for all costs of reclamation and long-term maintenance custody. Title II mills are those that were in operation after the effective date of the act, and reclamation is the responsibility of the owners. As of the year 2000, 23 Title I sites had completed surface reclamation and two others were in progress. Of the 29 Title II sites, 16 had completed surface reclamation, 11 sites had performed partial reclamation, and two others were still in operational status with no reclamation. One Title II site was never operated and has been dismantled outside of regulatory jurisdiction. (International Nuclear Inc., 2000)

Reclamation Requirements

To those practitioners and regulators who have worked on reclamation of coal and non-uranium hard rock sites, the uranium mill reclamation requirements must seem to be extraordinary. The sole objective of uranium mill reclamation is "permanent isolation of tailings and associated contaminants" (NRC 1982a); the objective of reclamation in other mining industries is restoration to some form of productive use, in which isolation of contaminants is only one element. The NRC has usually interpreted the requirements of 10 CFR 40 Appendix A for protection against release of byproduct to mean prevention of *any* release of tailings, in which the contaminant of primary concern is radium, under any circumstances; i.e. near-zero probability of release. Most state reclamation standards for other types of milling facilities call for protection against release of tailings according to some level of probability greater than zero, expressed in terms of protection against the effects of a design event such as the 100-year, 24-hour storm. Table 1 compares the reclamation requirements for uranium mills to those typical for metals mining.

The most striking difference between the standards for reclamation of uranium mill sites and the standards for other mining industries is the degree of conservatism required in both 10 CFR 40 Appendix A and the NRC's implementing guidelines. Although

Table 1. Differences in key reclamation requirements of uranium mill sites and metal mine/mill sites.

Uranium Mills	Metal Mines/ Mills
• Reclamation design life of 1000 years	• Reclamation design life of 100 years, typically
• Zero release of byproduct material	• Some factor of safety (e.g.; 2-3) against byproduct release
• No revegetation required except as needed for erosion control	• Revegetation required as a necessary element of post-mining land use
• Complete decontamination or on-site burial of equipment required	• Salvage and reuse of equipment allowed
• Demolition and on-site burial of buildings required	• Salvage and reuse of building components allowed
• Soil cover designed primarily to prevent erosion and limit emission of radon gas	• Soil cover designed to control erosion and infiltration and to support vegetation
• Maximum tailing impoundment sideslope is 5H:1V	• Maximum slopes based on structural and erosional stability
• Reclaimed site is permanently withdrawn from future productive use	• Productive post-mining land use is a primary objective

some evaluations of risk to human health and the environment are allowed in the statute and rules, in practice risk assessment is seldom utilized. The exception is ground water contamination issues, where the NRC has considered risk when evaluating whether alternative concentration limits (for uranium, radium, selenium, molybdenum, etc.) can be granted where the maximum concentration limits would be extremely difficult to achieve. The requirement for a design life of 1000 years (NRC 1982a) has the effect of requiring that the reclamation design for uranium mills be based on the most extreme events, specifically the Probable Maximum Precipitation event and the maximum probable earthquake. For protection against radiological exposures, reclamation design must be based on the principle of reducing exposure risks to levels as low as reasonably achievable. The conservatism of uranium mill reclamation requirements is evident from a closer look at the specific requirements for erosion protection, cover design, outslope design, and land withdrawal and surveillance.

Erosion Protection

The half-life of radium, 1660 years, means that it decays very slowly and produces radiation and radon gas for a period of time well beyond the design life of common manmade works, usually 50 to 100 years. When this fact is combined with the zero release standard for isolation of the byproduct, an exceptionally stringent erosion protection requirement emerges. The primary release mechanism for byproduct particles (tailings) is erosion by running water, so the NRC has established standards and guidelines for design of erosion protection that have been compiled and summarized most recently in NUREG-1623 (NRC 1999). No manmade materials are allowed; a layer of sound, durable rock must provide erosion protection unless no suitable rock is available, in which case a thick layer of soil may be used if designed to withstand 1000 years of erosion before breaching. The rock must have a durability score of at least 80% of the maximum possible combined score consisting of specific gravity, soundness, absorption, and hardness. If the rock has a score of less than 80% but more than 50%, it may be used if oversized by the difference between the score and 80%. This requirement is difficult to satisfy at many uranium mill locations because the predominant rock types are sedimentary sequences in which the sandstones are friable and weak.

Erosion protection, whether rock or soil, must be designed to resist erosion under the peak erosional stresses that can be expected in the 1000-year design life. Hydrometeorological records are not long enough to support prediction of the 1000-year precipitation event. Consequently, the NRC requires that rainfall and runoff models use the Probable Maximum Precipitation (PMP) storm and the resulting Probable Maximum Flood (PMF) event (NRC 1982a). Erosion protection must be sufficient to survive these events. For rock covers this means that the rock must be large enough to remain in place under shear stresses of peak flow, a once-ever condition that could be expected to last a few minutes at most. For erosion control of non-uranium sites, a maximum rate of soil loss, calculated by an empirically based method such as the Revised Universal Soil Loss Equation, is the typical method for erosion control design (Hutchison and Ellison, 1992).

Cover Design

The criteria of 10 CFR 40 also contain some specific requirements for covering mill tailings. Tailings must be covered with soil to limit radon gas emissions to a flux not greater than 20 pCi/m^{2}s (pico Curies per square meter per second). Only earth materials are permitted in the cover; no manmade materials may be used. Radon is a decay product of radium, which occurs naturally with uranium and is left behind in the tailings as a result of milling. The parameters that control radon flux include radium concentration, emanation coefficient, diffusion coefficient, water content, density, porosity and thickness of the tailings and cover soil. Little can be done to change these properties in the tailings; therefore, selection and placement of cover soils is critical in achieving the 20 pCi/m^{2}s limit. If the properties of the cover soils cannot be characterized to a statistically acceptable level, the NRC requires that default parametric values be used in the cover design (NRC 1999). Some of these default values are very conservative. For example, in the author's experience with cover design, tested long-term water content of clay cover soils ranges from 10% to 18%, but the default value is 6%. Emanation coefficients, a measurement of the rate of radon release from a source material, typically range from 0.1-0.2 for sandy tailings to 0.4-0.45 for tailing fines (slimes), but unless supported by statistically valid test results, a default value of 0.35 must be used (NRC 1989). However, it is very expensive or physically impossible to sample and test enough tailing and soil material to establish a statistically defensible value for every parameter, so default values have been used for the designs of many tailing covers. As a result, uranium tailiug covers range in thickness from 1.5 m to almost 5.0 m, with 3.0 m being typical (International Nuclear Inc., 2000). For non-uranium tailings, regulations usually allow use of geomembranes and geotextiles, and a cover need be only thick enough to limit infiltration, prevent erosion, and support vegetation. Non-uranium covers vary widely, from 1.3 m to 5 m, but most are less than 2.0 m (Hutchison and Ellison, 1992).

Outslope Design

Uranium tailing impoundments must be recontoured at closure to create outslopes not exceeding 5H:1V, or 20% grade (NRC, 1982). The selection of this maximum value was arbitrary and not attributed to any specific analysis of erosional or structural slope stability. All of the uranium tailing impoundments were initially constructed with much steeper outslopes, commonly 2.5H:1V or 3H:1V for constructed berms and angle of repose for hydraulically placed tailings, so substantial earthwork was required to recontour the impoundment outslopes (International Nuclear Inc., 2000). In fact, if the original outslope is 2.5H:1V, five times as much earthwork volume is needed to produce a 5H:1V final slope as a 3H:1V final slope, and 90% more cover is needed for the 5H:1V slope versus the 3H:1V slope.

Land Withdrawal

UMTRCA and 10 CFR 40 require that title to each uranium mill site and byproduct materials residing there be transferred to a) the U.S. government, b) to the state if it has regulatory authority under agreement with the federal government (agreement state), or c) to the Indian tribe on whose land the site exists. This requirement is intended to ensure that human health and the environment will be protected in perpetuity from the radiological hazards residing on the mill sites after reclamation. Essential to this protection are restriction of access, preservation of isolation of byproduct materials, and long-term surveillance. The federal government, through UMTRCA and 10 CFR 40, has gone on record as stating that any post-mining land use would be inconsistent with the protection of human health and the environment, so each uranium mill site will be preserved as a uranium byproduct repository, exclusive of any other use. Exceptions are made for those few sites that have been completely cleared of byproduct (e.g., Durango and Salt Lake City mills) and thus released for other uses. Land withdrawal of uranium mill sites contrasts sharply with non-uranium sites where the primary reclamation objective is productive post-mining land use.

To ensure that byproduct isolation is maintained, the federal government, agreement state or tribe will own each reclaimed uranium mill site, and that government entity will conduct long-term surveillance of the site. The funding for this surveillance will come from the DOE in the case of the Title I sites and from the former licensees of Title II sites. Each site's surveillance fund will be at least $250,000 in 1978 dollars, with required funding calculated assuming 1% annual interest earned on the fund to cover annual surveillance costs in perpetuity (NRC, 1982a). Post-reclamation monitoring requirements vary from state to state, but non-uranium site monitoring requirement usually have a finite time period tied to a measurable standard of reclamation success (e.g., revegetation) for release of the reclamation bond.

Reclamation Costs

The reclamation requirements described above are equally applicable to all uranium mill sites, both Title 1 and Title II, at least in theory. In fact, the actual costs of Title I site reclamation, both average costs per site and total costs, have been substantially higher than the corresponding costs of Title II site reclamation, as illustrated by Figures 3 and 4. This is so despite the fact that Title II mills processed nearly 10 times as much ore (Figure 1) and produced four times as much U_3O_8 (Figure 2) as Title 1 mills. The explanation for this disparity lies in the difference in reclamation management and in the level of conservatism enforced by the regulatory agencies.

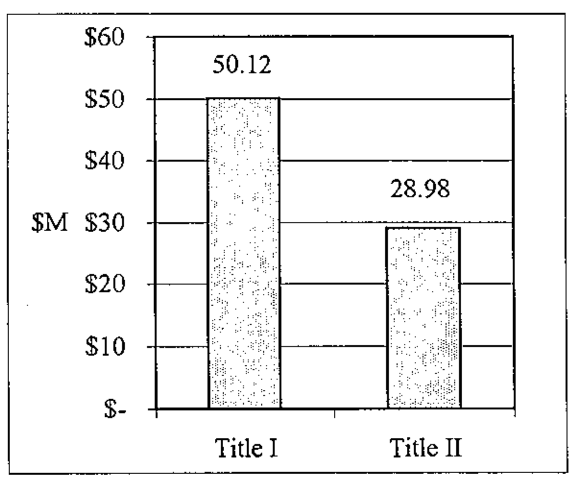

Figure 3. Average mill site reclamations costs. (International Nuclear Inc., 2000)

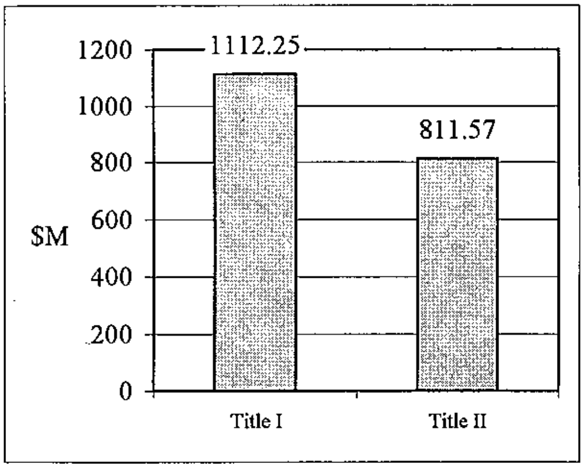

Figure 4. Cost of reclamation of all mill sites (International Nuclear Inc., 2000)

The Title I mills were reclaimed under the Uranium Mill Tailings Remedial Action (UMTRA) program in accordance with UMTRCA. The DOE set up a three-tiered management structure for the UMTRA program – DOE at the top, then a Technical Assistance Contractor (TAC), and a Remedial Action Contractor (RAC). DOE provided overall programmatic guidance and budgetary control, the TAC performed site studies and developed conceptual reclamation plans, and the RAC performed detailed studies and designs as well as construction management (International Nuclear Inc., 2000). Each tier had large staffs, many institutional and technical procedures, and both the TAC and RAC costs included profits. Added to this was the NRC practice of requiring greater conservatism in the reclamation of Title I sites, partly because they were funded by government money but also because of the DOE's aversion to residual risk at sites that it reclaimed (personal communications with NRC staff, 1994).

The NRC staff recognized that the cost of Title II mill reclamation would be borne entirely by the owners/licensees, with some compensation from DOE to those mills that had produced uranium for the Atomic Energy Commission for defense purposes. Therefore, in general, less conservatism in design was required in reclamation of Title II mill sites. However, in the experience of the author and others involved in Title II reclamation (International Nuclear Inc., 2000), the difference in reclamation costs between Title I and Title II sites is attributable mostly to efficiency of management of Title II reclamation. Title II licensees, being private enterprise (with one notable exception discussed below), were bottom-line oriented and motivated to minimize reclamation management costs.

The relative effectiveness of Title II reclamation management and cost control is evident not only in the difference in the average costs of reclamation of Title I versus Title II sites but also in the difference between the reclamation cost per metric ton of ore processed (Figure 5) and uranium oxide (U_3O_8) processed (Figure 6) by Title I and Title II mills. Although Title II sites generally benefited from economies of scale of much more ore (and, therefore, tailings) processed and uranium produced, the more than five-fold cost difference is attributable primarily to more cost-effective reclamation management. In general, Title II site owners managed reclamation using in-house staff with one level of management assigned to the site. Site management reported directly to corporate or regional management without intermediate levels (International Nuclear Inc., 2000). In some cases a consultant was hired to managed reclamation, especially if corporate staff was too small to provide an in-house site manager.

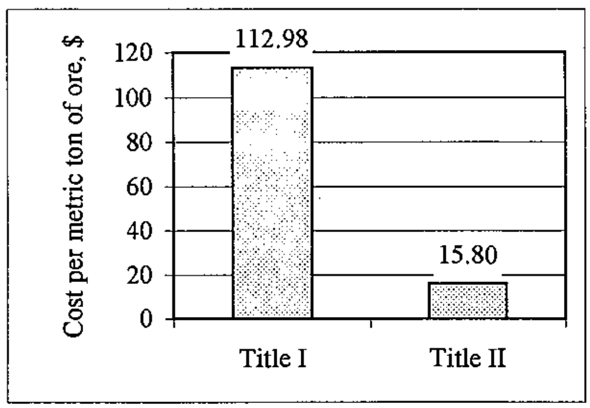

Figure 5. Average cost of reclamation per ton of ore processed (International Nuclear Inc., 2000)

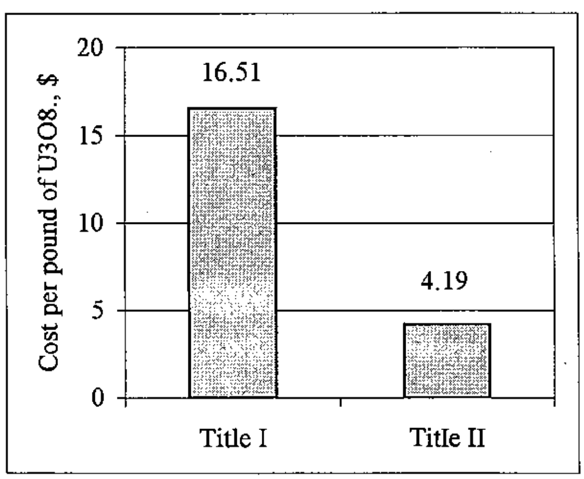

Figure 6. Average cost of reclamation per pound of U_3O_8 produced (International Nuclear Inc., 2000)

Figure 7 illustrates the variations and contrasts between individual sites in terms of the amount of uranium produced and the cost of site reclamation. With a few exceptions, the Title II mills produced much more uranium for fewer reclamation dollars. The one notable exception is the Monticello mill, represented by the square near theleft margin of Figure 7 at a cost of $256M. Monticello is technically a Title II mill because it was operating after 1967; however, it is owned by DOE and was operated by a contractor. Therefore, DOE is the licensee and is responsible for reclamation under Title II but is using essentially the same reclamation management approach as the Title I UMTRA program – a dramatic illustration of the difference in costs of reclamation by government and by private enterprise.

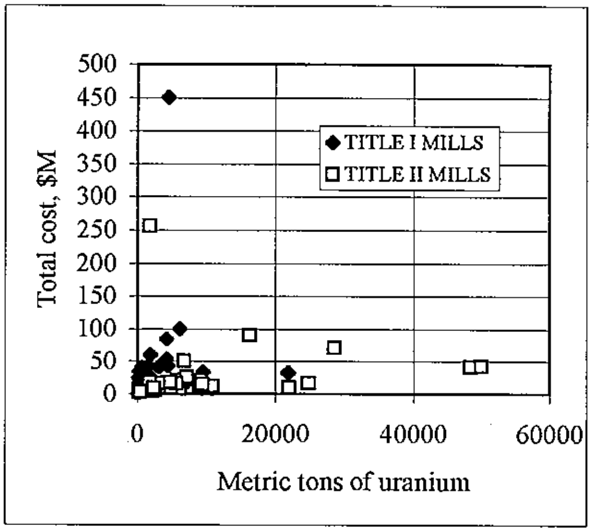

Figure 7. Reclamation cost versus uranium (U_3O_8) produced by individual site. (International Nuclear Inc., 2000)

Conclusion

Reclamation of uranium mill sites has followed a set of standards that are different from standards for other mining industries, requiring more conservatism in pursuit of different objectives. Absolute isolation for extraordinarily long periods of time is very expensive, as illustrated by the cost data presented here. Reclamation practitioners in non-uranium industries may not find the specifics of uranium mill reclamation standards and costs particularly relevant to their own assignments, but two lessons may be. The first is that any reclamation measure that must satisfy a design life beyond the period of historical reference, 50 to 100 years, of necessity will have to include a substantial amount of conservatism to account for the time-related uncertainty. The second lesson is that very large reclamation projects can be accomplished without very large management costs, but the likelihood of this decreases as the levels of management increase.

References

DOE (U.S. Department of Energy), 1978. 42 USC 88, Uranium Mill Tailings Radiation Control Act (UMTRCA), Decommissioning of U.S. Uranium Production, PL-95-604. Access through www.eid.doe.gov/cneaf/nuclear/decom

EPA (U.S. Environmental Protection Agency), 2000. 40 CFR 192 Health and environmental protection standards for uranium and thorium mills. National Archives and Records Administration, Access through http://frwebgate1.access.gpo.gov/cg-bin

Hutchinson, I.P.G., and R.D. Ellison, Editors, 1992. Mine Waste Management, Chap. 8. Lewis Publishers

International Nuclear Inc., 2000. Data Compilation and Analysis of Costs Relating to Environmental Restoration of U.S. Uranium Production Facilities. Prepared for the U.S. Energy Information Administration, U.S. Department of Energy

NRC (U.S. Nuclear Regulatory Commission), 1954. 42 USC 23, Atomic Energy Act. Access through www.nrc.gov/NRC/CFR

NRC (U.S. Nuclear Regulatory Commission), 10 CFR 40, 1982a. Title 10 Code of Federal Regulations Part 40. Domestic Licensing of Source Material. Appendix A

NRC (U.S. Nuclear Regulatory Commission), 1982b. Nuclear Waste Policy Act, as amended, PL-97-425. Access through www.public.iastate.edu

NRC (U.S. Nuclear Regulatory Commission), 1989. Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers. Regulatory Guide 3.64. Office of Nuclear Regulatory Research

NRC (U.S. Nuclear Regulatory Commission), 1999. Design of Erosion Protection for Long-Term Stabilization. NUREG-1623. Office of Nuclear Material Safety and Safeguards, Washington, D.C.

Uranium Institute, 1997. UI Facts: The Uranium Fuel Cycle – Early Uranium Mining in the United States. File C/02-U/I-97. Access through www.uilondon.org