Remedial Action at the Moab Site -- Now and for the Long Term: Letter Report

Committee on Long-Term Institutional Management of DOE Legacy Waste Sites: Phase 2, National Research Council

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Board on Radioactive Waste Management

June 11, 2002

Jessie Roberson
Assistant Secretary
Office of Environmental Management
U.S. Department of Energy
Washington, DC 20585

Dear Assistant Secretary Roberson:

At the direction of Congress, you asked the National Academies to assist the Department of Energy (DOE) in developing a plan for remediation of the Moab Site. This site, located adjacent to the Colorado River in Moab, Utah, contains a pile of roughly 12 million tons of uranium mill tailings and contaminated soils. The National Research Council, the chief operating arm of the National Academies, charged its Committee on Long-Term Institutional Management of DOE Legacy Waste Sites: Phase 2 with providing the requested assistance (see Appendix B of the accompanying report for the committee roster). Specifically, based on the congressional directive, the committee was asked to provide technical advice and recommendations to assist DOE in objectively evaluating costs, benefits, and risks associated with remediation alternatives for the Moab Site, including removal or treatment of radioactive or other hazardous materials at the site, ground-water restoration, and long-term management of residual contaminants. This letter summarizes the committee's major findings and recommendations. The accompanying body of the report elaborates on these, focusing primarily on a critical examination of the technical basis available to DOE for selecting a remediation plan for the site. As explained below, and in the body of the committee's report, the committee concludes that the current technical basis is not adequate to support a decision at this time.

DOE faces a decision between two main alternatives for remediation of the Moab Site: stabilize the pile in place or relocate the pile. All of the specific remediation options are variations on these two alternatives. Other aspects of the site remediation can be understood in relation to the decision between the main alternatives. The committee concludes that a closure path for the Moab Site is not ripe for decision because:

- *the pile, the Moab Site, and possible sites for a relocated disposal cell have not been characterized adequately;*
- *the options for implementing the two primary remediation alternatives have not all been identified or sufficiently well defined;*
- *the risks, costs, and benefits of the major alternatives have not been adequately characterized and estimated; and*
- *the long-term-management implications for each option have not been described.*

The committee further concludes that the additional data and analyses needed to enable a decision can be developed with a limited, focused effort.

Based on these conclusions, the committee makes the following recommendations: (I) DOE should undertake further, but bounded, investigations of several unresolved questions related to science and engineering in order to arrive at a sound remediation decision. (II) DOE's decision-making process should recognize the connections and potential tradeoffs between short- and long-term actions. (III) DOE should critically examine important assumptions and conclusions in its analyses of the two primary alternatives, examine the likelihood that they might be invalid over the relevant time frames, and reassess the risks in this new light. (IV) DOE should continue to plan remediation of the site in a way that explicitly involves the public, consistent with good risk-based decision-making practice. (V) DOE should draw more explicitly from its own experience in managing tailings piles in developing its plan for remediation at Moab. (VI) Issues that will not result in a net difference between the remediation alternatives (e.g., issues that require the same action under either remediation alternative) should not confuse the remediation decision-making process. These recommendations are further explained below, and documented in detail in the body of the committee's report.

Much of the body of the committee's report raises questions regarding the stabilize-in-place alternative. This is an incomplete focus, however, and could produce a misunderstanding of what DOE needs for its decision on a remediation alternative. The committee, like DOE, has worked from the information available, closely examining aspects of stabilizing the pile in place because that alternative was developed more extensively. Less attention has been devoted to the relocate alternative because DOE has only a superficial knowledge of most of the sites under consideration for the relocate alternative and of the impacts of transporting the tailings. Therefore, fuller development of alternatives is needed. Until the relocate alternative is better characterized and the committee's findings and recommendations are addressed, it is premature to decide that one site is better than another or that one remediation alternative is better than another. In part for these reasons, the committee's report does not identify a preferred remediation alternative. In addition, that decision involves tradeoffs among human-health risk (public and worker), environmental hazards, costs (including opportunity costs), and other relevant considerations. While the committee makes recommendations about what factors should be considered in making these choices, the decisions themselves are properly made by elected and appointed government officials.

I. DOE should undertake further, but bounded, investigations of several unresolved questions related to science and engineering in order to arrive at a sound remediation decision.

Over the years, the former site owner, a bankruptcy trustee, and the U.S. Nuclear Regulatory Commission (U.S. NRC) have worked with several contractors to analyze different aspects of the pile and the site. The information in these studies is insufficient to provide an understanding of the health and environmental risks and other matters that are needed to inform the decision. The documents and reports preceding DOE's involvement were prepared to support a license amendment to close the site by capping the pile in place. U.S. NRC had to decide whether to approve that particular application; it was not charged with identifying and selecting the *best* approach for remediation, accounting for all of the relevant factors. DOE is not responsible for the previous studies, and only limited new studies could be completed for the committee's review, because DOE only received funding for work at the site in July 2001.

DOE does, however, have responsibility for ensuring that the information upon which it bases the remediation decision is sufficient and of high quality. The committee recommends that DOE undertake a bounded process of fact-finding and analysis before reaching a final decision on site remediation. The committee finds that previous studies either do not address or do not adequately answer a set of questions that the committee sees as critical to assessing each alternative. These questions are discussed in detail in Sections III and V of the body of the committee's report. DOE should set priorities among these questions, addressing first those that most affect the remediation decision process and that are most likely to yield relevant results. These additional analyses should not be viewed as yet another postponement of site cleanup, but rather as the necessary background for a well-founded and expeditious decision.

II DOE's decision-making process should recognize the connections and potential tradeoffs between short- and long-term actions.

The committee suggests that the ultimate objective at the Moab Site should be to implement remediation and management measures that have the best reasonably achievable probability of being protective of human health and the environment for the duration of the hazard, taking into account relevant economic and societal factors. Federal regulations (40 CFR 192) adopt 1000 years as the design objective for the maintenance of human isolation of mill tailings from the environment. The regulations require that this objective be met "to the extent reasonably achievable," and set a lower bound for control of "at least" 200 years. These are ambitious goals, even though they fall far short of the full duration of the hazard.

Lower levels of remediation in the near term typically leave greater residual long-term hazards, which may increase the need for, the importance of, and the costs of long-term actions. The committee recommends that DOE assess each alternative for disposition of the Moab pile on the basis of its entire life-cycle, including the demands for long-term institutional management (LTIM) actions, where LTIM comprises the total system of protection, including contaminant reduction, contaminant isolation, and long-term stewardship. Thus, such an assessment would specifically include consideration of the residual risk when the near-term remediation actions at the site are complete, the LTIM measures required, the likely duration of these measures, the consequences of the failures of such measures, and the total social costs expended. DOE should consider all of these factors in establishing the balance between near-term cleanup and long-term measures, as well as in designing the LTIM measures, themselves. Long-term considerations do not necessarily outweigh short-term concerns (e.g., cost and remediation risk), but they should be identified, evaluated, and any tradeoffs explicitly identified and considered as part of the decision.

III. DOE should critically examine important assumptions and conclusions in its analyses of the two primary alternatives, examine the likelihood that they might be invalid over the relevant time frames, and reassess the risks in this new light.

The future risks from the stabilize-in-place alternative will depend on the long-term stability of the pile, the durability of the cover system, the longevity of society's memory regarding hazards at the site, the distribution and extent of contamination in the subsurface, the ability of engineered barriers to protect against movement of the course of the Colorado River toward the pile, and the persistence of organizational capabilities to respond to failures in the pile's integrity. In the current analysis, these issues are addressed by generally assuming that all engineered and natural systems will work as expected and that institutional memory will endure. The potential for these assumptions to be wrong, and the consequences if they are, need to be considered in more detail. These matters are discussed in Section V of the body of the committee's report.

An example of an important assumption that should be reviewed at the Moab Site is DOE's acceptance of the U.S. NRC's finding that the risks that the Colorado River will intercept and carry away a portion of the mill-tailings pile are small and that this eventuality can be addressed by engineered measures. In contrast, it is the committee's view that it cannot be assumed that the course of the Colorado River will remain in its current position over the next 1000 (or more) years. While one cannot predict the timing of river migration (over the coming millennia or in the next several decades), the committee sees it as a near certainty that the river's course will run across the Moab Site at some time in the future, unless engineered barriers prevent it from doing so. In addition to appropriate consideration of the probability that the river will change course, the consequences if such an event were to occur have been examined only superficially. Accordingly, DOE should assess the risks—both probabilities and consequences—associated with river-pile interactions over time. If the stabilize-in-place option is selected, explicit consideration of this failure scenario is necessary, and the risks may warrant a plan for dealing with such failures.

IV. DOE should continue to plan remediation of the site in a way that explicitly involves the public, consistent with good risk-based decision-making practice.

The National Research Council has advised in previous studies that decisions that involve risk management should involve the stakeholders from the earliest phases of defining the problem through the final decision. "Adequate risk analysis and characterization … depend on incorporating the perspectives and knowledge of the interested and affected parties from the earliest phases of the effort to understand the risks. The process must have an appropriately diverse participation or representation of the spectrum of interested and affected parties, of decision makers, and of specialists in risk analysis, at each step." (p. 3, [NRC 1996]) Public participation (including both the local public and the broader, national public) can bring important issues, concerns, perspectives, and information to the attention of decision makers in a timely manner, resulting in better decisions. In addition, extensive collaboration with the public increases understanding of the decision bases and helps create support for the decisions ultimately reached.

Involving the public has particular value at Moab because of the duration of the cleanup. DOE anticipates that contaminated ground water will require treatment for decades to meet the baseline regulatory standards, regardless of the remedy selected for the pile. Involving the local community during that period reduces the likelihood that the site's dangers will be forgotten in the longer term, and that the site would be used in inappropriate and dangerous ways. Public involvement and community support or acceptance can also form a foundation for the creation of effective institutions and practices for long-term management of residual hazards at the site.

The committee finds that Moab is a promising location to pursue the recommendations of previous committees of the National Research Council addressing public participation in risk-based decisionmaking. It is particularly noteworthy that the Moab community seems ready to accept a final resolution that would keep the tailings in their own county, albeit at a location farther from the river and the town. This demonstrates a degree of receptiveness to DOE's role and an apparent atmosphere of civic responsibility in which DOE has an opportunity to work productively with local stakeholders.

The openness of DOE staff, working with local and state government and the community, has brought a positive attitude to a long-festering problem. This is a strong beginning.

V. DOE should draw more explicitly from its own experience in managing tailings piles in developing its plan for remediation at Moab.

The Moab Site is the newest, the largest, and potentially the most expensive member of the population of UMTRCA Title I sites. Every one of these sites except the Moab Site has already been put through the process of selecting and implementing a remediation plan. Thus, a comparative analysis of options, risks, and decisions at Moab in light of existing information on other UMTRCA sites could provide some important perspectives. Questions that DOE might ask regarding other sites, that could aid decision making at the Moab Site, include: Have the models used to project the behavior of the disposal cells at other sites proved to be accurate to date? Have the groundwater cleanups encountered significant surprises? Do the local communities continue to be supportive of DOE's long-term surveillance and maintenance activities? How can the high costs for some of the projects, measured in terms of risk reduction per dollar spent, be lowered at Moab? Have measures for LTIM been effective at these sites so far? Are there other non-UMTRCA sites with similar characteristics that have been remediated using the alternatives proposed at Moab (i.e., moved or stabilized in place) and, if so, what lessons can be learned from these sites? Are there sites where the initial decision had to be reevaluated or reversed and, if so, why?

Although DOE has shared gross cost estimates and first-order cost breakdowns with the committee, the committee believes that a more thorough examination of past experiences will provide DOE with both technical and social lessons helpful in planning remediation and long-term management at Moab. The committee particularly recommends that DOE examine cost data (initial bids and final costs) to identify where the costs significantly exceeded early estimates, which could help DOE judge whether cost estimates for the remediation alternatives at the Moab Site are reliable and could be improved.

VI Issues that will not result in a net difference between the remediation alternatives (e.g., issues that require the same action under either remediation alternative) should not confuse the remediation decision-making process.

Some issues do not produce a preference for either remediation alternative, and should not confuse the remediation decision-making process. An example is the threat to potential habitats for endangered species such as the Colorado pikeminnow. Such threats can probably be mitigated temporarily by simple remedies that will be required under either alternative. For the long term, it appears that ground-water remediation will be required for reasons independent of the endangered-species issue. If both the temporary measures and the ground-water remediation are required and can be fulfilled under any remediation alternative, then there is no net difference related to endangered species.

In conclusion, DOE has made a useful start to its evaluation of the Moab Site and the options for remediating it, and the committee appreciates the active cooperation of DOE staff in the committee's study. The body of the committee's report provides more detailed findings and recommendations that the committee hopes will help those specifically charged with planning and carrying out the site remediation. Thank you for the opportunity to assist in addressing this important issue.

Sincerely,

Kai N. Lee
Chairman, Committee on Long-Term Institutional
Management of DOE Legacy Waste Sites: Phase 2

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I Introduction

The Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 transferred ownership of, and responsibility for, the Moab Site from the trustee of the bankrupt owner to the U.S. Department of Energy (DOE). This site, located adjacent to the Colorado River in Moab, Utah, is a former uranium mill and contains a pile of roughly 12 million tons of tailings and contaminated soils. The Act also required DOE to ask the National Academy of Sciences to provide technical advice and recommendations to assist DOE in objectively evaluating costs, benefits, and risks associated with remediation alternatives for the Moab Site, including removal or treatment of radioactive or other hazardous materials at the site, ground water restoration, and long-term management of residual contaminants. (See Appendix A for more background on the area and the site.) The National Research Council, the chief operating arm of the National Academies, charged its Committee on Long-Term Institutional Management of DOE Legacy Waste Sites: Phase 2 (hereafter referred to as "the committee") with carrying out those tasks. This report (hereafter referred to as the "committee's report") is the committee's fulfillment of that request.

To carry out its investigation, the committee held an information-gathering meeting on January 14-15, 2002, in Moab, during which the committee heard from DOE; the local public; state, local, and federal elected and appointed officials; regulators; researchers; and industrial stakeholders and other advocates (see Appendix B for the meeting agenda). The committee also examined information on the site as well as information related to the management of uranium mill tailings, remediation technologies, and local habitats and ecosystems. The committee's observations, findings, and recommendations are described briefly in the summary letter at the beginning of the committee's report. The letter and the body of the committee's report have been peer reviewed in accordance with the procedures of the National Academies.

DOE assumed ownership of the Moab Site in October 2001 and provided the committee with the Draft Preliminary Plan for Remediation of the Moab Site (DPPR) [DOE 2001] soon thereafter. The DPPR provides background on the site, simple descriptions of remediation alternatives with an initial screening with respect to costs, and overviews of regulatory requirements. It also identifies criteria by which DOE plans to evaluate the alternatives and a preliminary evaluation of the main alternatives. The criteria listed pertain to effects on human health (public and worker) and the environment, regulatory consequences, long-term and short-term issues, acceptability to stakeholders, and costs. DOE appears to be taking a sensible approach and has identified the right categories of factors to look at, but the information available on many of these factors is incomplete. The DPPR relies on previous studies by contractors for the Atlas Corporation, which owned the site, the U.S. Nuclear Regulatory Commission (U.S. NRC), which regulates uranium mills and their tailings, and PriceWaterhouseCoopers, which was trustee for the site after Atlas' bankruptcy. While the U.S. NRC's environmental impact statement and the other reports constitute a substantial body of work, they concern or grew out of the Atlas Corporation's application for a license amendment to allow Atlas to cap the pile in place. U.S. NRC had to decide whether to approve that application, but it was not trying to select the best approach for remediation, accounting for all the relevant factors.

DOE is now in the process of deciding how to remediate the site and dispose of the wastes, some of which can pose a hazard to health and environment far into the future. There are two principal alternatives for remediating the pile of mill tailings: to stabilize the pile in place or to relocate it. All of the specific remediation options—those considered by DOE and those proposed by interested parties—are variations on these two main alternatives.[1]

II Scope of the study and overall recommendations

Plans for the remediation of contaminated sites and for the location of disposal cells are always developed with incomplete information—the list of data that could be collected is lengthy, gathering the data is costly, and there are many unknowns, especially regarding the long-term future of the site. What then does DOE really need to know in order to make a sound public policy decision? The committee offers advice on the scientific and technical dimensions of that question, but notes two important limitations: First, neither the committee nor DOE has had much opportunity to augment the information already available concerning the site and the alternatives for its management. Second, the committee's review is circumscribed and focused. The committee is not advising on *all* relevant dimensions of the remedial choices. Instead, it offers comments only on those matters of natural and social science and engineering that fall within its charter and its members' expertise.

Based on its limited review, **the committee concludes that the current technical basis is not adequate to support a decision at this time. The committee further concludes that the needed data and analyses to enable decision can be developed with a limited, focused effort. The committee therefore recommends that DOE undertake further, but bounded, investigations of several unresolved questions related to science and engineering in order to arrive at a sound decision.** The committee's list of unresolved questions is divided into four areas below. This list is not exhaustive: in particular, while some of the issues have been raised before,[2] the committee emphasizes issues that are pivotal to DOE's decision, but that do not seem to have been given appropriate attention in the existing record left by the former site owners and regulators, or in DOE's studies and plans as of January 2002.

In making a decision about the cleanup and closure of the Moab Site, the committee believes that DOE faces unresolved questions in four areas:

1. Characterizing the primary remediation alternatives.

2. Addressing concerns raised under the Endangered Species Act.

3. Understanding interactions between water and the pile, and designing a cleanup plan for contaminated ground water.

4. Addressing challenges associated with long-term institutional management.

Discussions on the first three areas are provided in Sections III, IV, and V of the committee's report. Discussions of the last area appear throughout, but the most focused discussion of this area appears in Section V subsection C. The unresolved questions are followed by some technical observations about the Moab Site and its remediation, provided at the end of the committee's report, in Section VI.

[1] There is always the potential for new technologies and new alternatives to arise in the future, but in the case of uranium mill tailings the committee judges that these would be likely to create new specific remediation options, rather than new main alternatives.
[2] See, for example, the comments on U.S. NRC's Draft Environmental Impact Statement found in Appendix A of [U.S. NRC 1999].

Before addressing unresolved questions concerning the remediation alternatives, it is worth noting some general observations about the duration of hazards that apply to any, and all, remediation options.

The solids in the uranium mill tailings pile are heterogeneous, but various measurements (Table 2-9, [SMI 2001] and Tables 3.2 and 3.3, [SRK 2000]) yielded Ra-226 concentrations that are above the 5 pCi/g and 15 pCi/g limits for surface and subsurface Ra-226, respectively, in the applicable U.S. Environmental Protection Agency (EPA) standard [40 CFR 192]. Ra-226 and its parent, Th-230, are decay products of natural uranium, are a minor concern if they are inhaled as airborne dust or ingested, and, although they may yield substantial radiation doses to persons in long-term close proximity to the tailings, are not the major concern for potential future risk. More importantly, Ra-226 gives rise to Rn-222, a relatively short-lived (3.8-day half-life), gaseous isotope. While Rn-222 itself causes little harm (see [NRC 1986] and [NRC 1999]), its gaseous form enables it to escape the rocks, sands, and other materials where it is produced. Rn-222 decays into a series of short-lived progeny that produce the majority of the dose and risk from inhaled radon. Anywhere that Rn-222 accumulates for even a short time will have Rn-222 progeny in comparable concentrations (with respect to radioactivity). Based on studies of tailings piles and sites with Ra-226 concentrations above background, it is virtually certain that the dominant risks from the site will be due to inhalation of Rn-222 and its decay products.

Because Ra-226 is continuously produced by decay of Th-230 in the pile, the evolution of Ra-226 concentrations is controlled by the half-life of Th-230, which is 75,400 years. Few data are available on Th-230 concentrations in the pile, but one would expect them to be similar to those of Ra-226, as they would have been in decay equilibrium in the ore.[3] Most Ra-226 concentrations in the samples at the site are in a range of 300 to 600 pCi/g, which would require about five Th-230 half-lives or roughly 375,000 years to decay to the EPA subsurface limit. In addition, the residual natural uranium in the tailings solids continues to decay and generate new Th-230 and Ra-226. This decay will result in a future equilibrium concentration of Ra-226 in the tailings solids that, while lower than the current concentration, will remain higher than the EPA subsurface standard of 15 pCi/g.[4] After the Th-230 has decayed to a concentration in equilibrium with U-238, the concentration of Ra-226 will decline at a rate defined by the half-life of U-238, which is 4.5 billion years. The tailings solids, thus, represent a hazard that essentially lasts forever.

Other considerations that the committee believes should be factored into a good decision process at Moab are local, regional, and national interests. The large remediation costs and the duration of the hazards mean that choices need to be made in a way that discharges DOE's obligations of management to both the nation and the local community, which is likely to be affected for a long time, no matter which choices are made. For example, DOE has a responsibility to select an alternative that meets the EPA standards, which demand the best reasonably achievable assurance of satisfactory performance for up to 1000 years. DOE should also recognize that there is no physical basis for a line to be drawn at 1000 years; indeed, as

[3] If a decay product in a decay chain is not actively removed, and if its parent is longer lived than the product, then parent and the decay product eventually reach a decay equilibrium, where both radionuclides have the same specific activity (concentration of radioactivity). Such an equilibrium would have been reached for uranium, thorium, and radium in the uranium ore. Some leaching processes remove more thorium than others [NRC 1986]. But unless thorium is intentionally extracted with the uranium, to a first approximation the concentration of radioactivity from Th-230 in the tailings should be similar to that from Ra-226.

[4] The committee references the subsurface limit as most relevant to tailings in a disposal cell, although the more restrictive surface limit is more directly related to acceptable health risk [U.S. EPA 1983]. Uranium concentrations in the Moab tailings solids (Table 2-8 [SMI 2001]) range from 18 to 140 mg U/kg solids. Any value above 45 mg U/kg will result in an equilibrium Ra-226 concentration that exceeds the EPA subsurface limit.

described above, the hazards to humans and ecosystems from the mill tailings will last far longer than the period of regulatory compliance. For significant hazards that endure for very long times, or essentially in perpetuity, DOE should consider whether it has a responsibility to consider the legacy beyond the regulatory time frame. The committee has no criteria of its own to recommend, at this point in its deliberations, in making decisions about the longer-term hazards, except that they should be evaluated and actively considered in reaching a final decision concerning the site. These considerations apply to every part of every remediation alternative that leaves an enduring hazard.

Much of the committee's report raises questions regarding the stabilize-in-place alternative. This is an incomplete focus, however, and could produce a misunderstanding of what DOE needs for its decision on a remediation alternative. The committee, like DOE, has worked from the information available, closely examining aspects of stabilizing the pile in place because that alternative was developed more extensively. Less attention has been devoted to the relocate alternative because DOE has only a superficial knowledge of most of the sites under consideration for the relocate alternative and of the impacts of transporting the tailings. Therefore, fuller development of alternatives is needed. Until the relocate alternative is better characterized and the committee's findings and recommendations are addressed, it is premature to decide that one site is better than another or that one remediation alternative is better than another.

III Characterizing the primary remediation alternatives

Recommendation:

Uncertainties in key issues related to the remediation alternatives should be addressed with a bounded and focused investigation. Addressing these uncertainties will make it possible for DOE to make a scientifically sound comparison between the principal alternatives; namely, to stabilize-in-place or to relocate.

DOE's most detailed comparisons of the principal alternatives in its DPPR were based on monetary cost estimates. These estimates are uncertain (DOE estimates that real costs could be up to 25 percent higher [DOE 2001]), various options for implementing the relocate alternative might reduce its costs, and issues raised in the committee's report could affect the cost of both options. As a result, the committee concludes that the DPPR cost estimates do not serve as a reliable discriminator between the two principal alternatives. In addition to quantifiable and non-quantifiable economic considerations, there are also significant uncertainties in the risks to human health (both public and worker) and the environment of alternative courses of action, as well as differences in the social value ascribed to the alternatives under consideration.[5] In order to understand the risks associated with the primary remediation alternatives, one must characterize the pile and any sites involved. This has not been done adequately. It is not possible for DOE to entirely eliminate the associated uncertainties, but DOE can determine which are the most important ones to consider and can reduce them through actions suggested below. In the priority areas identified below, the committee believes it possible to improve understanding quickly and within the bounds of economic prudence. Those improvements would, in turn, inform judgments that are scientifically defensible and support a remediation decision that is more likely to gain the support of the local community and the nation.

[5] In any case where tradeoffs are made between dissimilar impacts (e.g., benefits in the form of peace-of-mind and benefits in the form of exposures avoided), one compares the value society places on those impacts.

IV Addressing concerns raised under the Endangered Species Act (ESA)

Finding:

Similar ground-water remediation measures will be needed to protect endangered species under either of the primary remediation alternatives, so concerns raised under the Endangered Species Act do not yield a preferred alternative. If variances from baseline standards are sought or if significant recontamination is not prevented for the long term, then the issue of protective standards should be revisited.

Ammonia[6] in ground water is reaching the Colorado River along the boundary of the Moab Site. The site abuts a reach of the Colorado River that is habitat for two species of fish listed as endangered under the Endangered Species Act (ESA): the Colorado pikeminnow or squawfish (*Ptychocheilus lucius*) and the razorback sucker (*Xyrauchen texanus*) [USGS 1998] [USFWS 1998] [SMI 2001] [DOE 2001]. During about a four-week, low-flow period after spring high water, normally dry shorelines adjacent to the site remain submerged and might serve as nurseries for finfish larvae and juveniles. The Colorado pikeminnow and the razorback sucker are among those that might try to use these temporary backwater pools as nurseries [DOE 2001] [US FWS 1998]. Because of the lower river flow, additional fresh water from the river is not available in the backwaters and the ammonia concentrations in the pools near the pile rise to levels that have been determined in laboratory tests to be lethal to larvae and juvenile fish of these species [USGS 1998]. Of the various contaminants in the ground water, only ammonia has been determined to be a threat to the endangered species, although concerns were raised about selenium as well [USFWS 1998]. Data on whether the endangered species actually would, or do, use the submerged shorelines at the site are inconclusive, but the U.S. Fish and Wildlife Service has declared the entirety of the 100-year floodplain of the upper Colorado River to be critical habitat for these species. The ammonia does show up in tests in the floodplain at the site, so it is affecting critical habitat [USFWS 1998].

The ammonia comes from a plume of contaminated ground-water under the pile, which contains several contaminants. The ammonia originated mostly as an additive used to precipitate uranium and other metals in ore processing (see p. 1-8 and 1-9, [SMI 2001] and p. 29-31, [NRC 1986]). Shepherd Miller estimates that eight hundred million gallons of ground water would require treatment to address the ammonia problem [SMI 2001]. This ground water appears to need cleanup to meet ground-water standards under the regulations based on the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) [40-CFR 192] for uranium, molybdenum, nitrate, and various other contaminants [DOE 2001]. The committee was told that the Utah State Department of Environmental Quality (Utah DEQ) regulates surface water and, where ground water interacts with surface water, Utah DEQ can set concentration limits for ground water [Morton 2002]. Cleanup would be needed to meet Utah DEQ's water-quality standards, which seem to require that ammonia concentrations at the ground-water—surface-water interfaces be reduced by two or three orders of magnitude (see, e.g., [USGS 1998]), which would protect the endangered species.[7]

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[6] The combined concentration of ammonia and ammonium ions, rather than simply the ammonia concentration, was measured at the Moab Site [DOE 2001]. The term "ammonia" in the committee's report refers to total ammonia, which includes both ammonia and ammonium ions.

[7] Total ammonia measurements at near-shore areas within the river at the bank ranged from roughly 5 mg/L to as high as 224 mg/L [USGS 1998] for total ammonia as nitrogen. The Utah State Water Quality Criterion for total ammonia as nitrogen (at pH = 8.5 and temperature of 25°C) is 0.32 mg/L [UDEQ 2002], although it is not clear that this is the standard that would be applied. Laboratory tests results and calculations for the Colorado pikeminnow indicate the chronic 90-day minimal effect level (0.01%

Ground-water cleanup is expected to take decades under any remediation alternative [DOE 2001]. In the meantime, however, simple and relatively inexpensive measures appear to be available to mitigate the harm (actual or potential) to the endangered species. The committee has been informed by DOE staff that water from upstream in the Colorado could be diverted to the submerged shorelines—the backwater pools—and used to dilute the ammonia to levels that would not harm juvenile fish. While the committee has not explored the regulatory or technical feasibility of this approach, no objections were raised to the approach at the committee's information-gathering meeting. This approach should, therefore, be considered as an option for near-term action. If this mitigation can be carried out, there would appear to be no additional concerns under the ESA, provided that the dilution is carried out every year until the ground water is cleaned up.

If, indeed, the ground-water plume must be cleaned up under any remediation alternative in order to meet Utah's water quality standards, then protection of endangered species should not determine the choice of how to deal with the tailings pile. This point applies more broadly: **Issues that will not result in a net difference between the remediation alternatives should not confuse the remediation decision-making process.** Hazards to endangered species are only irrelevant to the decision-making process if applicable requirements for cleanup and protection of ground water do in fact protect the affected species and if those requirements are met. Although baseline standards have been shown to be protective, supplemental standards and alternative concentration limits might be allowed by the regulatory bodies. The issue should be revisited if DOE is considering seeking variances from the baseline standards, or if significant recontamination is not prevented for the long term. The requirement to continue temporary mitigations should, of course, be seen as an additional cost and institutional burden of any remediation alternative that does not permanently clean-up ground water at the site.

The committee notes that only few, indirect data are available on whether the endangered species actually could use the submerged shorelines at the site if the ammonia were not present, so the threat posed to these species by ammonia in the pools is unknown. DOE should investigate this further. A survey of the benthic community within the reach upstream and downstream in the Colorado River would help determine if there is an insult from the site. Regarding the pools themselves, ammonia concentrations may be toxic, but other characteristics of the toe-of-slope habitat, such as temperature and topography, may also be limiting factors making the habitat unfavorable. These have not, to the committee's knowledge, been explored and would help with assessing the ecological risks at the site.

Finally, while the ESA is a law protecting species that are listed as endangered, it is also a mechanism for protecting the habitats and the ecosystems of which those species are a part. If the concern is about habitat and ecosystems, then an assessment of the ecological risks at the site should involve an examination of the effects on other members of the ecosystem, not just those that are currently listed as endangered. The site appears to be sparsely populated, so the effects may not be large.

V Understanding interactions between water and the pile, and designing a cleanup plan for contaminated ground water.

Recommendation:

DOE should critically examine important assumptions and conclusions in its analyses, assess the probabilities that they might be invalid over the relevant time frames, and assess the resulting risks.

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mortality) to be 2.66 mg/L for total ammonia. Similar tests indicate 50% mortality for fish exposed to 18 mg/L for 72 hours [USGS 1998].

The committee has identified five assumptions and conclusions regarding the Moab Site that DOE should treat as hypotheses, examine critically, and justify explicitly before selecting a remediation alternative. These assumptions and conclusions are:

- Engineered barriers on the exterior of the pile would prevent significant infiltration of water, either from precipitation (under either principal alternative) or from flooding by the Colorado River (for the stabilize-in-place alternative), and thus would prevent further contamination of ground water.

- Floods and lateral migration of the river do not threaten long-term stability of the pile if it is stabilized in place.

- A social capacity for long-term monitoring of the site(s) and appropriate response to the failure of engineered barriers can be provided reliably, so that the risk and consequences of failures can be managed.

- Even if engineered and institutional defenses of the pile against encroachment of the Colorado River fail, loss of even a substantial portion of the pile into the river if it is capped in place would produce only small and transitory consequences downstream.

- The life-cycle cost of moving the pile is substantially higher than that of capping it in place, and there is no substantial difference in the cost of ground-water remediation and long-term management between the alternatives.

These assumptions and conclusions can be found throughout the DPPR (and some are specifically identified in Section 5.8, [DOE 2001]) and supporting documents. The committee believes, instead, that these should be treated as hypotheses that should be studied for Type II errors: In other words, given the incomplete evidence that each hypothesis is true, what is the risk of its being false? These hypotheses cannot be tested statistically in a conventional sense, nor can they be deterministically answered, but development of more understanding is both possible and warranted in each case.

It should be emphasized that the committee intends not to prejudge the outcomes of the investigations by identifying issues that apply more to the stabilize-in-place alternative than to the relocate alternative. The committee focuses on these issues, in part, because of the obvious presence of the Colorado River at the Moab Site. The focus is also, however, a result of the fact that other candidate sites and modes of transporting the tailings for the relocate alternative have not been examined in any substantial detail. As the alternative of relocating the pile is developed, an array of questions regarding the site for the disposal cell will also have to be examined in detail. Additionally, the probabilities and consequences of failures under each of the major alternatives will need to be considered.

DOE has extensive experience in remediation of uranium mill tailings sites, most of them in the Colorado Plateau environment in which Moab is located. The Department's record with these tailings sites forms a valuable body of experience, particularly with respect to costs and surprises. The committee notes that the costs and surprises at those sites may not be fully known for some time and DOE should take care in drawing comparisons. Nonetheless, while some further investigations at the Moab Site are needed, for some of the additional data that are needed DOE should draw from its past experience, as is recommended in its own program reviews (see, e.g., [DOE 1991]). Past experience with UMTRCA Title II sites would also likely prove informative. Data on these remedial actions might not, however, be as easy to acquire as data on the Title I sites, since DOE carried out the remediations in the latter case.

Each of the five assumptions and conclusions identified for further examination above are now discussed in more detail in the sub-sections that follow.

A Would engineered barriers on the exterior of the pile prevent significant infiltration of water, either from precipitation or from flooding by the Colorado River, and thus prevent further contamination of ground water?

Infiltration is potentially a problem because it could carry more contamination to the ground water [U.S. NRC 1999]. For the stabilize-in-place alternative, if substantial new ground-water contamination were introduced, then cleanup of the site would not have a clear end within the regulatory timeframe of 100 years for ground-water remediation, and beyond. Instead, remediation would become a periodic activity extended or repeated into the indefinite future. For the relocate alternative, substantial new ground-water contamination might also require remediation, and could result in the deterioration of otherwise unpolluted ground water.

The DPPR cites studies that conclude that the existing and previously proposed engineered barriers (a one-foot-thick compacted clay cover protected by several inches of sandy soil and a layer of rock armor) are sufficient to prevent significant infiltration of water into the pile, under the stabilize-in-place alternative [U.S. NRC 1997, 1999]. To address remaining concerns about infiltration through the cover, DOE has added a 5-foot-thick "soil protective layer" to the conceptual design of the cover described in the The Final Environmental Impact Statement by the U.S. Nuclear Regulatory Commission (U.S. NRC's FEIS) [U.S. NRC 1999] [DOE 2001]. However, it is the committee's opinion that the analysis and the additional measures may not adequately address the problem.

Infiltration might occur via two paths: through the cover and through the bottom of the pile. If the cover of the pile is compromised by erosion, desiccation or differential settling and faulting, or active removal (i.e., if the rocks and other materials in the cover were deemed valuable and people took them), then precipitation (and flooding if the pile were close to the Colorado River or another river) would reintroduce water to the pile. The potential for desiccation of a clay barrier is always a concern in arid/semi-arid climates. One function of the "soil protective layer," described above, is to protect the barrier layer from desiccation. The performance of UMTRCA disposal cells where this design has been employed in arid/semi-arid climates could be used to provide evidence that such a soil layer is effective in preventing desiccation of the underlying clay. DOE has used this approach at a few of its more recently remediated sites [Smith 2002].

The committee was told that DOE's general experience at other mill-tailings site suggests that the hydraulic conductivity of the cover should be expected to increase by one to two orders of magnitude over time [Edge 2002]. Thus, recharge rates of water infiltrating (or draining) through the pile could be substantially larger than now estimated. Impacts of such increases on ground water, and river-water quality in the case of the stabilize-in-place alternative, should be evaluated for the types of contaminants that contribute to ground-water contamination at the site, including inorganic compounds (ammonia, nitrate, sulfate, and dissolved salts), radionuclides, trace metals, and organic compounds. Also, it is hard to imagine a response to these events that does not rely in some way on active institutional management over the long term (i.e., beyond the regulatory timeframe of 100 years for active institutional management of ground water remediation).[8]

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[8] Neither the top flow cover system schematic (Figure E1, [DOE 2001]), the cover design for the cap-in-place alternative (Figure 2-1, [DOE 2001]), nor the relocation alternative (Figure 2-4, [DOE 2001]) show a drainage layer between the infiltration barrier and the protective soil layer. If designed and managed properly, such a layer might be used to reduce infiltration into the tailings via the cover. Indeed, drainage layers of this nature are frequently employed at RCRA Subtitle D landfills for such a purpose.

Infiltration of water into the pile at its base risks further ground-water contamination in the stabilize-in-place alternative, especially because no engineered liner is envisioned for the pile. U.S. NRC's FEIS states that the limiting hydraulic conductivity for water flow into the existing pile at its base is 10^{-6} cm/sec (p. 4-56, [U.S. NRC 1999]), and thus the volume of water entering the pile during river flood periods "would be greatly limited" and would result in "minor additions" of contaminants to the ground water. It is not clear whether or not such additions would exceed applicable regulatory requirements. Furthermore, such a low hydraulic conductivity might be justified if a sufficiently thick layer of fines (clay-size material) has accumulated across the entirety of the bottom of the pile. The evidence for such a continuous layer of fines is weak, however. A recent study (Figure 6.2, [SRK 2000]) suggests that both consolidated silt and unconsolidated silt exist at the base of the pile.[9] Moreover, if the pile is re-wetted, the analysis of metals (Table 5.8, [SRK 2000]) and radionuclides (Table 5.9, [SRK 2000]) in the pile's tailings solids indicate that both the consolidated, as well as unconsolidated, silt tailings could be potential sources of incremental contamination. Thus, the committee believes that the impacts of a possibly discontinuous layer in the unconsolidated silt on water infiltration into the pile (and subsequent discharge of dissolved contaminants) have not been adequately assessed. Further, DOE should consider the effects of Moab Wash as an episodic source of recharge that could potentially wet the contents of the pile.

Tailings are highly heterogeneous, both physically and geochemically, at various spatial scales as a result of variations in the source material (ore), ore processing (including aggressive physical and chemical treatment for extraction), differential deposition history, and differential aging under varying geochemical conditions. Even modest changes, such as erosion of bits in the machinery that grinds the ore, create different kinds of fines in different layers. This adds uncertainties in prediction of physical and chemical behavior, which affect pile stability and contaminant fluxes. DOE cannot be expected to have an exact knowledge of the composition of the Moab pile. But DOE's considerable experience with the management of uranium mill tailings at other sites will help to determine whether DOE can assume that the tailings can be modeled as regular ground-up rock or if more data should be collected to understand the likely long-term mechanical behavior of the tailings.[10] These data could be collected in conjunction with the tests supporting calculations of contaminant flux, recommended below. In addition, for any contaminated materials not yet in the pile (tailings and contaminated soils that are to be added to the pile for disposal), DOE should evaluate the impact of introducing new chemicals to the existing pile material. Specifically, the impact of new chemicals on the geochemical behavior of the pile should be considered, as well as its future behavior as a contaminant source. Clearly, this would require adequate characterization of the contaminated materials before they are emplaced in either the stabilized cell on the site, or the disposal cell at a new site.

The committee found no calculation of the extent of leaching of contaminants into new water (such as river water) infiltrating the pile, and partition coefficients (K_ds) may not have been measured or estimated for the tailings themselves. Rather, it appears that the contaminant flux out of the pile was estimated based on seepage (water) fluxes and the average chemistry of

[9] Note that these materials are referred to by inconsistent names throughout the report by Steffen Robertson and Kirsten [SRK 2000], the values cited for hydraulic conductivity of these materials in Table 4.4 exhibit a counterintuitive trend (showing increasing hydraulic conductivity with consolidation), and are inconsistent with other values cited within the report (see Figures 6.4 and 6.5, [SRK 2000]). Rather than raising the hope that one set of values or another corroborate an otherwise preferred outcome, these features should be cause for caution in relying on any of the data and analyses that the report provides without independently verifying the results.

[10] If, for example, silica gels, which are highly hygroscopic, were present in significant quantities in the Moab pile, then the tailings would be unlikely to be dewatered and would physically change with water infiltration into the pile. If present in sufficient quantity relative to minerals such as quartz, this could affect the viscosity of the tailings material, which could threaten the pile's stability. DOE can determine whether this could be a problem at the Moab Site.

tailings' pore fluids [SMI 2001]. While it is well-known that partition coefficients represent an imperfect model for describing the partitioning of contaminants between a solid phase and the interstitial fluid, the committee agrees that such values represent a reasonable means to attempt to predict dissolution or desorption of contaminants from the pile sediments. Shepherd Miller estimated K_ds for aquifer material to calculate the rates of contaminant flux into the river for scenarios with and without the pile present [SMI 2000], but no attempt has been made to calculate how much contaminant might partition into infiltrating water if the pile were flooded. Such a calculation should also consider pore fluids within the tailings and slimes, which could be transported into the river in the case of inundation. Given the heterogeneity of the tailings, the committee suggests that K_ds measured for many samples of tailings material be used to make bounding calculations of contaminant flux for inundation scenarios. Such calculations would be relatively straightforward to complete, and should be completed for all probable contaminants, not just uranium and ammonia.

There may also be significant impacts from re-wetting of the more permeable consolidated silts, which also appear to be in hydraulic connection with the native material at the base of the pile.[11] Furthermore, the role of the pile as a continuing source of contamination of the ground water due to its current water content is not well understood (p. 2-19, [DOE 2001]). As noted in the Shepherd Miller report (p. 2-6, [SMI 2001], it is not known how much tailings water has been brought to the surface under the de-watering actions carried out at the pile to date. Moreover, the water depth-profile and spatial variations within the pile are not well known [Wright 2002]. It has been estimated that about 1.2 million tons of the pile, located towards the center, may be composed of "slimes" that are still draining (p. 7-1, [SRK 2000]), but estimates of outflow from the pile are highly uncertain.[12] This in turn makes the ground-water remediation effort more uncertain than one for which the source term is known. DOE should try to put bounds on the present-day seepage rates from the pile. This seepage rate, once bounded, could be multiplied by an average contaminant concentration in the pile pore waters to estimate contaminant flux due to seepage, or multiplied by the maximum concentration in the pore waters to estimate an upper bound. Alternatively, a reactive transport model could be used to calculate contaminant flux out of the pile using K_ds for the tailings, taking into account heterogeneity of the sediments and pore fluids within the pile, but this would be a much more difficult task. Regardless of which calculation is used,[13] heterogeneity of sediments in the pile must be well-characterized to make such bounding calculations. Given that pore-water quality in the tailings was only sampled and analyzed at nine wells located within the pile, further sampling and analysis is warranted. All of these calculations could be framed more accurately if similar calculations for other piles were

[11] The illustration of the relocated site alternative given in Figure 2-4 of the DPPR shows a 1 foot reconditioned soil layer between the base of the tailings and the existing substrate. It is assumed that this soil will be a clay soil that can be derived from excavation at the relocation site (p. 2-13, [DOE 2001]). If this layer is to be used to protect the subsurface from any residual hazard posed by the tailings–including the ex-filtration of contaminated water–the integrity of this layer must be maintained for the duration of the hazard. The addition of a leachate collection system above the reconditioned soil layer, as is mandatory for RCRA Subtile D landfills, might aid in monitoring the performance of the new cell in its initial years of operation.

[12] The Shepherd Miller report [SMI 2001] explicitly discusses the problems with estimated seepage rates from the Steffen Robertson and Kirsten (SRK) report [SRK 2000]. The Shepherd Miller report notes that SRK expects the volume reduction in the pile resulting from dewatering to be on the order of 15 million cubic feet, but SRK's model of the ground-water flux out of the pile yields 60 million cubic feet. "The total volume of groundwater leaving the tailings pile from the bottom can not exceed the total volume of consolidation" (p. 3-9, [SMI 2001]). After finding that the higher fluxes did not match measurements of contaminants at the site, Shepherd Miller adjusted the values down to 15 million cubic feet to correct for this problem. The discrepancy, however, calls into question the overall reliability of the dewatering analysis.

[13] The simpler calculation might be acceptable if the contaminant mass loading to the aquifer from the pile is shown by such a first order calculation to be truly insignificant.

used as models, and if similar data at other tailings piles were used to estimate the expected variability in chemical composition of waters and sediments. While controlling the behavior of the pile will be somewhat simplified by emplacement of a cover, it will be difficult to have confidence in the dewatering and consolidation measures,[14] and in the adequacy of the bottom layers of the pile as barriers to infiltration (or exfiltration), without further study.

The committee cannot say whether infiltration actually will or will not be a problem with any particular cell design under either remediation alternative. The data and analyses are not sufficient for a judgment, which is why the committee recommends these further investigations, which should focus on differentiating between the alternatives.

B Do floods and lateral migration of the river threaten the long-term stability of the pile if it is stabilized in place?

Ensuring the long-term stability of the pile is the major goal of the UMTRCA regulation [40 CFR 192] and is necessary under the stabilize-in-place alternative to prevent the tailings from entering the river. If the consequences of loss of stability of the pile are deemed unacceptable over some time period, then the possible mechanisms for loss of stability discussed below should be examined for that period.

The middle of the pile, as noted above, appears to be composed of moist, unconsolidated sediments, referred to by the investigating contractor as unconsolidated silt (Figure 6.2, [SRK 2000]), or "slimes." Continued consolidation of these materials after the cover has been emplaced could result in damage to the cover. The Moab Mill Reclamation Trust, formed after the bankruptcy of the Atlas Corporation, hired Steffen Robertson and Kirsten to develop a dewatering plan both to remove water in the pile as a source of further ground-water contamination and to consolidate the pile prior to emplacing the cover [SRK 2000]. Efforts to dewater the pile might not completely consolidate the sediments, and indeed the efforts to date have been less successful than anticipated (p. 1-9, [DOE 2001]).[15]

Floodplain boundaries around the pile have not been determined [DOE 2001], but "on several occasions, flood waters have risen from 3 to 4 ft above the base of the pile" (p. 4-13, [DOE 2001]). The DPPR states that the geotechnical stability of the pile has been demonstrated by analyzing slope stability during short-term loading during construction, and long-term static loading and dynamic loading due to seismic events (p. 1, Appendix E, [DOE 2001]). DOE should also consider, however, the possibility that floodwaters, either rising up the side of the pile, or receding, could also mechanically destabilize portions of the pile. Under sudden flood conditions, water levels between the inside and the outside of the pile will not be in equilibrium. If there is a large enough difference between these levels, upward ground-water flow could result in seepage forces that threaten the strength of the soil within the pile (see, e.g., [Coduto 1999]). River hydraulic analyses indicate that the river level would rise to a height of 29 feet on the side slope of the pile during the probable maximum flood (p. 2-2, [DOE 2001]). Consideration should be given to whether a flood of this magnitude could generate local upward hydraulic gradients, beneath the pile and around the toe of the pile, that are large enough to compromise the local soil stability.

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[14] If the pile is not adequately dewatered and consolidated, then differential settling resulting from heterogeneity in the pile might affect the integrity of the cover.
[15] Only part of the dewatering plan was carried out. The wick drains installed in the pile are less effective than anticipated, in part because less cover material (soil) was loaded on top of the pile, resulting in lower pressures inside the pile and less outflow. The wick drains have also served as a path for water transport back into the pile (p. 2-6, [SMI 2001]).

Lateral migration of the Colorado River towards the tailings pile also could lead to its destabilization. A report prepared for the Atlas Corporation by Mussetter Engineering, Inc. [Mussetter Engineering 1994] concluded that the potential for migration of the modern-day Colorado River channel is low for several reasons: the exit and entry points of the river to the Moab-Spanish Valley are bedrock-controlled; coarse-grained alluvial fans and deposits in the valley provide armoring to protect the river bank adjacent to the pile against lateral migration; in addition, the Moab marsh complex on the east bank of the river provides storage capacity for overbank flow, thereby reducing maximum shear stresses on the river bank adjacent to the pile. The Mussetter report also concluded that the west bank of the river (the bank adjacent to the tailings pile) is undergoing lateral accretion, not erosion, at present.

The conclusion that there is low potential for lateral migration appears to be overly optimistic in view of available evidence and scientific understanding of river hydraulic processes. Lateral movement of the river channel away from and towards the pile has been observed since this stretch of the Colorado River was first surveyed for possible dams, in 1944. Indeed, near Mile 990 [USGS 1948] of the Colorado River, which is just south of the pile, the channel appears to have migrated some 400 meters east between 1944 and 1980 [USGS 1980]. Between 1980 and 1999, the channel appears to have moved approximately 150 meters back to the west [Landsat 1999]. The nearest approach of the present-day river channel is located approximately 230 meters southeast from the toe of the pile [DOE 2001].

Utah Geological Survey mapping of Colorado River terraces [Allison 1994] indicates that the river has migrated substantially since Pleistocene time, and at one point the river may have been located west of where the tailings pile is (rather than east, as the river is now). This is based on gross geologic investigations at the site, such as the presence near the pile of gravels and other materials that might have been deposited by the river in the past (p. 2-14, [U.S. NRC 1997]).

Although the river entry and exit points to the valley are pinned by bedrock portals, within the valley the river flows across an alluvial bed. The general behavior of alluvial-bed rivers is well understood—the channels meander and, over time, points of lateral accretion become points of erosion. The bed of alluvium extends across the site and underlies the entire pile. Consequently, the present-day behavior of a river channel along a particular reach is not necessarily a good predictor of future behavior.

U.S. NRC found the erosion-mitigation measures for the stabilize-in-place alternative to be acceptable [U.S. NRC 1999]. Essentially the same measures are presented in the DPPR [DOE 2001]. The main mitigative measure is a rock apron to be installed around the pile to protect the pile and its clay barrier. If the river erodes the bank and migrates to the base of the apron, rocks (riprap) that make up the apron are intended to fall onto and reinforce the eroding bank. (This measure is sometimes referred to as "launching riprap.") The thickness of the apron and the size of the rocks that are to make up the apron were selected based on the potential for scour, erosion, and deposition by the river, in order to avoid eroding the bank again, after the riprap has fallen. In particular, the riprap size was selected based on water velocities (shear stresses) calculated for the most erosive flood envisioned for the current river configuration [Mussetter Engineering 1994], and on Army Corps of Engineers models [U.S. NRC 1997].

However, the river-flow dynamics and shear stresses are affected by the path of the river; by river discharge, which depends on the climate; and by the continued presence of dams on the Colorado River. There is a strong possibility that both natural and man-made forces will change those conditions over the period of regulatory concern. Natural variation in the flow of the Colorado River over a time scale of centuries has not been examined for this purpose and becomes increasingly important, especially as one looks toward and beyond the one-thousand-year time frame.[16] Failures of upstream dams on the Colorado River and its tributaries could result in sudden and dramatic, if temporary, changes within decades or centuries. Finally, global climate change is expected to have a major impact on the flow characteristics of rivers around the world, and is expected to occur well within the relevant regulatory timeframe and duration of the hazard. As the only major river in a large region, the Colorado River can be expected to exhibit different flood frequencies and magnitudes as the global and regional climates change. The committee has not assessed these effects or their potential impacts on the current apron design, but the committee does believe that the design should be reexamined in light of these factors.

If the river were to intercept the apron, and if the launching riprap would not permanently halt the erosion of the bank due to multiple floods, then someone would have to have the knowledge, ability, and resources to tend and repair the apron (as is required with most engineered barriers to river migration) for the indefinite future, or bear the consequences of the tailings entering the river. DOE should ascertain whether a design that could require repair would satisfy the regulatory requirement for design life of the disposal cell.

In addition, erosion of the pile by floods in Moab Wash remains a concern, if the pile is stabilized in place. The wash drains directly against the north shoulder of the tailings pile. Cursory observations made during the committee field trip showed boulders being eroded in a small erosion gully near the toe of the pile. At least one boulder in the alluvium exceeded 0.5 meters in diameter. These most likely were carried by a flood originating in Moab Wash in the Holocene or late Pleistocene. DOE should investigate whether flows of such a magnitude would undermine the stability of the pile, including "launching" rip-rap.

C *Can social capacity for long-term monitoring of the site(s) and appropriate response to the failure of engineered barriers be provided reliably, so that the consequences of failures can be managed?*

Human action will be necessary during the regulatory timeframe to exclude people from the site, monitor the performance of the disposal cell, detect intrusions, and respond to failure; and beyond the regulatory timeframe also, to maintain the cap, regardless of which remediation alternative is selected. While DOE has identified the need for long-term management of the pile, the long-term-management implications have not been described for each remediation alternative. Consequently, as part of its information gathering and analysis to support decision making, DOE should examine the effectiveness of long-term management for the two principal remediation alternatives.

DOE should begin by taking into account the fact that human action includes the activities of persons beyond the Department and its contractors. The role of public understanding, together with collaboration with state and local governments and other stakeholders, is rooted in the fact that DOE's ability to control what happens at the sites where it works is limited. The committee states, in the summary letter and at the end of this section, its opinion that the social setting of the Moab Site affords unusual opportunities to work with the local community. At the same time, DOE retains legal responsibility for physical conditions at the site and is responsible for the expenditure of significant amounts of taxpayer funds. Investing those resources in a way that strengthens institutional controls and social responsibilities for the Moab Site is an important component of the choices that DOE is making.

Fortunately, the initial interactions between DOE and the community appear to have been positive. DOE was welcomed to Moab by citizens at the committee's public meeting in January.

[16] Appendix A provides a plot from the U.S. Geological Survey [USGS 2002] of annual peak streamflow for the Colorado River near Cisco, Utah, over the last 85 years.

Members of the public saw in DOE an agency that has remediated other uranium mill-tailings sites. Moreover, the openness of DOE staff, working with local and state government and the community, had brought a positive attitude to a long-festering problem.

The National Research Council has advised in previous studies that decisions that involve risk management should involve key stakeholders from the earliest phases of defining the problem through the final decision. "Adequate risk analysis and characterization … depend on incorporating the perspectives and knowledge of the interested and affected parties from the earliest phases of the effort to understand the risks. The process must have an appropriately diverse participation or representation of the spectrum of interested and affected parties, of decision makers, and of specialists in risk analysis, at each step." (p. 3, [NRC 1996]) Public participation (including both the local public and the broader, national public) can bring important issues, concerns, perspectives, and information to the attention of decision makers in a timely manner, resulting in better decisions. In addition, extensive collaboration with the public creates support for the decisions ultimately reached, or at least increases understanding of unpopular decisions. DOE should continue to plan remediation of the site in a way that explicitly involves the public, consistent with good risk-based decision-making practice.

Social capacity is required in three different time periods, each with its own institutional situation. In the near term—a period lasting roughly a decade, according to the DPPR—DOE will make a decision and implement the stabilization-in-place or relocation of the pile. In either case, contaminated ground water at the Moab Site would require remedial actions lasting decades to meet baseline standards [DOE 2001], well beyond the period when the remediation of the pile itself is to be completed. In the time period beyond a century, the hazards from the tailings will require continued isolation—under either remediation alternative—by a combination of engineered barriers and social actions; that responsibility lasts indefinitely.

It may be prudent to assume that institutional controls cannot be maintained in that open-ended time period. Institutional controls are not envisioned in the applicable regulations, except implicitly in the assumption that the federally owned site(s) will remain under federal control and will not be developed without federal permission. Given the hazards and their timeframes, the best reasonably achievable solution for the Moab Site would involve a well-integrated set of near-term remediation actions and long-term institutional management (LTIM) actions, where LTIM comprises the total system of protection, including contaminant reduction, contaminant isolation, and long-term stewardship [NRC 2000]. A well integrated set of LTIM actions will recognize the potential tradeoffs between near-term remediation actions and LTIM commitments: Lower levels of remediation in the near term typically leave greater residual long-term hazards, which may increase the need for, the importance of, and the costs of long-term actions. DOE's decision-making process should recognize the connections and potential tradeoffs between short- and long-term actions. The previous study on LTIM by the National Research Council [NRC 2000] recommends that "[o]ther things being equal, contaminant reduction and removal should be preferred over contaminant isolation, and either is preferable to the imposition of stewardship measures that have a high risk of failure" (p. 98, [NRC 2000]). The fallibility of physical and institutional controls is addressed throughout that LTIM report. Studies by the Environmental Law Institute [Pendergrass 2000] and others [Probst and McGovern 1998] have reached similar conclusions, observing that most institutional controls fail rather quickly (within decades) after their establishment.

In the near term, while the pile is being put into its closed state, DOE can build relationships with state and local governments and stakeholders, so as to foster a social setting that will promote continued surveillance and repair and other protective activities as needed. Together these groups can also develop contingency plans to provide the institutional and financial capabilities that would be needed for a credible response to future failures of controls. The durability of those arrangements would be tested during the remainder of the ground-water cleanup phase, when large expenditures by DOE will have ended and the site(s) will be closed except for the ground-water remediation facilities. As the Committee on Remediation of Buried and Tank Wastes (this committee's predecessor) observed, the task of LTIM entails continual learning, as the specific conditions at sites change, both in natural and social dimensions [NRC 2000].

The threat of human intrusion into the pile deserves special attention, particularly given the history of uranium mill tailings in the United States. First, ignorance could result in use of a capped pile as a rise on which to build houses or hotels with a view, water slides, or parking lots with a vista–to name three actual land uses in the Moab area. The rising demand for land in this currently popular recreational destination increases the likelihood of such development, in the absence of effective physical and institutional controls. The Moab Site is potentially valuable real estate, making institutional controls more difficult to impose, especially if they rely on local governments, which are often under pressure to develop land to boost the economy. Second, people might intrude to gain access to the cap or the tailings material itself. The cell, wherever it is, is likely to be covered with riprap that will be brought in from elsewhere at some expense. Its inherent value might make it tempting to future nearby residents who need high-quality stone. The tailings might attract intruders who want to recover minerals, or use the tailings as sand and fines for cement. Such unauthorized uses of tailings from exposed piles have occurred, and they prompted Congress to pass the act under which all of these management activities are carried out, namely UMTRCA.

Institutional management and controls, if they are effectively employed, can reduce the probability of a misuse of the tailings or a degradation of the engineered barriers, perhaps even over long periods. Society's confidence in public agencies and contractors to persist in the effective administration of institutional and operational measures across a number of management generations diminishes faster than does society's confidence in many engineered barriers [Applegate and Dycus 1998]. There is, however, no good evidence that illuminates the question of how durable institutional controls can be expected to be. What is now known about the social aspects of long-term management and institutional controls comes primarily from case studies, such as toxic wastes at Love Canal [McNeill 2000] and rapid loss of warning signs of mercury contamination at the Oak Ridge National Laboratory [Applegate and Dycus 1998]. That experience leads to general guidance of what to avoid in planning for long-term environmental protection (see [Pendergrass 1996] for a summary). In sum, while one should design the best system of long-term management that one can, the extent to which one should rely on institutions in the long term depends heavily on the consequences of its failure.

U.S. NRC assumed, in its review of the Atlas Corporation proposal, that memory of the site and of what is needed to tend it (including technical records in readable, obtainable formats) would be sustained [Fliegel 2002]. DOE's Grand Junction Office (DOE-GJO) houses the Long-Term Surveillance and Maintenance Program (LTSM Program), which is responsible for maintaining the remediated Title I UMTRCA sites. DOE-GJO assumes that it will remain present, responsible, and capable of performing its tasks, and that the Office will maintain the institution's memory. The LTSM Program's reports detail some of the elements of long-term institutional management, but they are notably silent on the time frame during which reliable LTIM can be sustained. The regulatory minimum design life of the disposal cell is 200 years, which is nearly as long as our Republic has existed. The regulatory design goal is 1000 years, and the institutions are exceedingly rare which have continuously performed a particular task–or even existed–since the year 1002. Of course, as noted in the opening pages of the committee's report, some hazards associated with the materials in the pile will persist forever.

Thus, neither the memory of the mill tailings, nor the institutional controls to prevent human intrusion, nor the social capacity to repair engineered barriers can be assumed to be in place and sustainable in the future. That does not mean that the pile is likely to harm human health or the environment. Rather, our society's capacity to *guarantee* that harm will be prevented is limited. Moreover, it is impossible, as a practical matter, to estimate the probability of institutional failures. There may be identifiable differences, however, in the consequences of failure of a relocated pile or a pile capped in place.

In this light, **it is important that DOE's judgments about the institutions responsible for, and sharing in, the management of the tailings pile be explicit and that DOE plan, taking into account the likelihood of eventual institutional failures for each remediation alternative.** What is relevant in DOE's choice is not a guarantee, for which there is no scientific basis, but a social contract, which can be nurtured, among those who are likely to be affected and the guardians of the tailings. That social contract can be shaped by public involvement, and it entails many matters lying beyond the scope of this committee's charter.

The committee advises DOE to consider the coming decades, during which remedial actions are being carried out at the Moab Site, as a trial period for its LTIM plans in which it can test some of the hypotheses that have been made in its remedial plans. For example, if continued site ownership by DOE is not likely to be sustained, there is time to test the workability of alternate arrangements while site and ground water are cleaned up. The committee finds that Moab is a promising location to pursue the recommendations of previous committees of the National Research Council. From the materials made available to the committee, from conversations with DOE and community officials, and from observations on the committee’s site visit, it is apparent that a broad cross-section of the local, regional, and national community is willing, interested and capable of participating in DOE’s characterization and decision making processes. It is particularly noteworthy that the Moab community seems ready to accept a final resolution that would keep the tailings in their own county, albeit at a location farther from the river and the town. This demonstrates a degree of receptiveness to DOE’s role and an apparent atmosphere of civic responsibility in which DOE has an opportunity to work productively with local stakeholders.

D *Would loss of even a substantial portion of the pile into the Colorado River produce only small and transitory consequences downstream?*

Analyses of losses of tailings into the Colorado River should more closely examine the consequences of radioactive materials reconcentrating downstream by sedimentation processes, resulting in exposures to humans.

U.S. NRC assessed the consequences of twenty percent of the pile (1.9 million metric tons) entering the river in a hypothetical flood that it determined is a “low probability scenario.” Based on its calculations, U.S. NRC concluded that water quality would be harmed temporarily, as in any flood. The enduring hazards are associated with redeposition of the tailings. These were treated qualitatively:

> Where tailings accumulate in quantity in floodplains, backwater areas, beaches, etc., they could pose a hazard for many years (without major remediation measures) to both persons who may use these contaminated areas, as well as to aquatic and terrestrial organisms. Agricultural, recreational, and other uses by humans of contaminated areas may be restricted until cleanup of such areas has been accomplished. (p. 4-60, [U.S. NRC 1999])

Moving water is a very efficient tool for sorting—examples include sorting by density differences such as exhibited in placer gold deposits and placer monazite (for thorium) deposits in California and Florida, respectively [Guilbert and Park 1986]. No plausible scenario produces uniform deposition; in fact, extreme heterogeneity in concentrations of tailings deposition can be expected based on differential deposition of particles of different sizes or different densities.

Graf found such heterogeneity in deposition in plutonium concentrations downstream from Los Alamos National Laboratory [Graf 1996]: Concentrations vary over more than four orders of magnitude within less than 1 km. Variations in concentrations between channel and overbank deposits at the same locality can vary by more than four orders of magnitude, and each class of sediment (e.g., channel deposits, overbank deposits) can show great variations within short horizontal distances. Variations can also result from differential dilution by clean sediments. For example, some "hot" sand bars might be diluted because they are downstream from a wash, while other "hot" sandbars might only infrequently be diluted because they are not situated near sources of clean sediment.

One conclusion to draw from these observations is that cleaning up after an event such as the U.S. NRC considers might be difficult and different from most of DOE's cleanups. The tailings solids that enter the river will be sorted by the river and deposited heterogeneously—high concentrations here, low concentrations there—and the localized hot spots on beaches and sandbars might not be in the same place from year to year (or even season to season). Such contamination could appear along the Colorado River from Moab to Lake Powell, requiring remedial action over a long period of time, if only to determine that the threat in a particular year or season is minimal or to declare certain areas off limits. (The capacity to undertake these actions is part of the LTIM discussed above.)

The ecological consequence of tailings entering the river, either quickly as a result of a flood, or gradually as a result of erosion, should also be considered. Of some concern is the potential impacts of sediments on river biota. Any large increase in the load of sediments on the riverbed could have an effect on the benthic community and, in the case of a massive flood, additional sediment load might damage the Matheson Wetlands Preserve, across the river. The survey of the benthic community suggested in Section IV would help assess the potential impacts additional sediments from the pile would have on that community and could help identify how long it would take for it to recover from such an insult.

Many people value the river for its religious and spiritual significance, its dramatic natural beauty, its importance as a water resource, its symbolic representation of the entire region, its importance as an ecosystem, and its centrality to the regional economy. Contamination on sandbars and beaches could have significant impacts on the tourism industry, which uses riverbanks and bars as camping areas for river runners. This stretch of the Colorado River is one of the most widely used, and most famous, white-water rafting and kayaking regions in the world. It is possible that the high concentrations possible with heterogeneous deposition would not be a significant hazard even to river guides, who are likely to have the highest exposures, but the committee recommends that DOE develop a better understanding of these potential risks and consequences and the expected long-term effects of movement of the pile into the river.

At the same time, the committee notes that one's ability to conceive of a high-consequence event does not necessarily demand radical action to avoid that event. One should also assess the probability of that event occurring along with its consequences, and thereby evaluate the risk over time. These factors together form a more complete understanding that can inform selection of a course of action. Whether the resulting risk is acceptable is, of course, the kind of policy decision that should be made by accountable governmental institutions like DOE and the Congress.

E *Is the life-cycle cost of moving the pile substantially higher than that of capping it in place, and is there almost no differential cost of ground-water remediation and long-term management between the alternatives?*

The cost difference between the cap-in-place option and the relocate alternative, assuming a new disposal cell at Klondike Flat, is estimated at approximately $250 million. At the January meeting in Moab, DOE indicated that while the cost estimates were the best it could generate in the time available, significant uncertainties remain, particularly with respect to long-term institutional management costs and the costs of ground-water remediation. Aspects of both the long-term management costs and ground-water remediation have been discussed, but the costs of ground-water remediation deserve further mention.

The DPPR states that "it is assumed that the ground-water remediation and compliance strategy will be essentially the same for the cap-in-place, treatment, or off-site disposal alternatives, with minor variations" (p. 2-19, [DOE 2001]). The variations are: alternative concentration limits apply to contaminants directly under the pile for the stabilize-in-place alternative, remediation might take longer if the pile remains on the site, and regulations require that more ground water and soil would require cleanup if the pile is relocated. DOE concludes that the cost difference for ground-water remediation between relocating and stabilizing in place, expressed as net present value, is $75,000 out of approximately $23 million (Table 2-3, [DOE 2001]).

This counter-intuitive conclusion is based upon several assumptions, such as: (i) the assumption that most of the uranium contamination is in soil where the mill buildings stood rather than in the pile (see p. 7, Appendix C, [SMI 2000]). (ii) The assumption that the rate of seepage flux of contaminants from the capped pile, when integrated over the lifetime of remediation, is insignificant compared to the contamination already in the ground water. (iii) The assumption that the rates of seepage fluxes of contaminants other than uranium and ammonia (the only two contaminants considered by Shepherd Miller for corrective action[17]) provide an insignificant flux to the ground water over the lifetime of remediation. These assumptions are important factors driving the conclusion that ground-water cleanup costs are the same under each primary remedation alternative. DOE should try to put bounds on the present-day seepage rates from the pile, which have not yet been established reliably (see footnote 12), and better assess whether these assumptions are valid.

If costs are to be an important element of the decision on a remediation alternative, then the cost estimates should be improved and ways to lower both relative and absolute costs for the remediation alternatives should be explored. The committee does not have great confidence in the cost estimates provided in the DPPR because of uncertainties and unresolved issues, such as those regarding the role of the pile as a possible complicating factor for ground-water remediation and the lack of differentiation in the institutional-control and other long-term-management requirements for the two major alternatives. Additional options for implementing the two principal remediation alternatives have not yet been explored in detail and might provide cheaper ways to implement the alternatives, thereby possibly shifting the potential balance and, in any case, saving money.

DOE's experience in remediating other UMTRCA sites could be quite helpful in this endeavor. In particular, the committee urges DOE to examine cost data (initial bids and final costs) to identify where the costs significantly exceeded early estimates, which could help DOE judge whether cost estimates for the remediation alternatives at the Moab Site are reliable and could be improved. DOE has shared gross cost estimates and first-order cost breakdowns with the committee. More detailed breakdowns will allow DOE to focus on costs that discriminate

[17] Page 1 of Appendix C of the Shepherd Miller report [SMI 2001] states that "Because the very limited aquifer below the site has never been a viable source of water for domestic consumption, the corrective action assessment does not focus on restoration of the aquifer. Rather, it focuses on providing greater protection for the aquatic species in the river." DOE might choose to take corrective action for other contaminants (see Table D2, [DOE 2001]). It cannot be simply assumed that cleanup of ammonia and uranium will also cleanup other contaminants.

between the alternatives. Care should be taken in drawing parallels, and DOE should recognize that the costs and surprises associated with LTIM may not be fully known, even for sites that have been closed for decades. The committee, nonetheless, recommends that DOE draw from its experience.

VI Observations about the Moab Site and its remediation

In addition to the overall evaluation, the committee provides several technical observations on particular aspects of the analyses that have been, or must be done, at the Moab Site. These observations are not exhaustive, and indeed some of them may not prove critical to a decision, but the committee provides them in the hope that they will assist DOE in its efforts.

A Passive measures for ground-water remediation

If baseline regulatory standards are to be met, ground-water remediation appears to be required irrespective of the decision made to move the pile or leave it on site (as is noted in the DPPR). The general approach set out in DOE's DPPR is to pump and treat the ground water along the corridor where ammonia might be killing larval and juvenile fish, which is thought to be the first place where negative impacts on biota occur. Installing a network of extraction wells to provide complete hydraulic capture of the contaminated plume may be feasible and should be considered. There is, however, a possibility that, if extraction wells were installed, the new local gradient may lift the underlying brine and actually make the situation worse for endangered species and other biota. A number of other innovative approaches that minimize the maintenance and aboveground treatment needs should also be considered. In particular, the use of passive approaches (e.g., permeable bio-reactive zones) for treating the plume should be evaluated.[18] While designing reactive zones appropriate for the scale of application at Moab poses novel challenges, DOE's Environmental Management Science Program has funded research on several innovative approaches for treating radionuclide-contaminated soils and sediments [DOE 2002], and some of these may also be useful for treating the contaminated plume at the Moab Site.[19]

There is also an opportunity at the Moab Site for treatment-system design to be based on a treatment-train approach (combinations of technologies) that provides a cost-effective solution at the appropriate location. The location at which compliance is assured may depend on the remediation alternative selected for the pile and whether effects on threatened and endangered species are determined to be a continuing concern at the site.

B Settlement analysis of the pile during dewatering

The settlement analysis of the pile during dewatering (Section 6, [SRK 2000]) assumes a linear elastic soil model for all materials within the pile, with the exception of the slimes, which were described by a non-linear elastic model. For a soil to behave elastically, in either a linear or a non-linear fashion, deformations of the soil under a load must be recoverable when the load is removed. In general, soil, and in particular unconsolidated soil, will undergo plastic (permanent) as well as elastic (recoverable) deformation under loading [Cheng and Yuan 1993]. There are many soil analyses available that can describe this behavior. The committee does not wish to single out one particular analysis as being more appropriate than another. The committee advises, however, that DOE examine the appropriateness of using an elastic soil model to

[18] DOE mentions permeable reactive barriers in its DPPR (p. 2-18, [DOE 2001]), but the barriers' potential role in the cleanup is not described and the committee heard little mention of them in presentations.

[19] Even passive approaches require maintenance and intervention from time to time. Reactive barriers require replacement because of saturation or degradation, and they can clog.

predict the settlement behavior of the pile during dewatering. DOE's experience in remediating other UMTRCA site should point to which models previously used to predict settlement behavior at other sites have worked well, and which have not.

C Ecological issues

There are potential ecological impacts of the pile, in addition to those on threatened and endangered species. The wetlands preserve across the river from the site is regionally significant habitat, and is protected from development. Modeled plumes from the site were shown to travel deeply into the ground water beneath the river, and to surface at varying locations. If such plumes exist then their impacts on the wetlands should be assessed. Monitoring wells and surficial presence of contaminants in the preserve would establish possible influence. Sampling of potential receptor species from different trophic levels for the presence of key contaminants may also be appropriate. During flooding stages, there is a continuous sheet of water from the pile toe through the wooded wetlands to the east. An understanding of transport of potential contaminants, including sediments, across the river during these events would be appropriate.

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Appendix A

Background on the Moab Site and Area

Background on the Moab Site and Area[20]

Driving into the city of Moab from Arches National Park, a visitor might not notice the pile of uranium mill tailings that sits just off the highway near the entrance to the Moab Valley. How does one miss a twelve million ton, 130 acre pile that rises nearly one hundred feet above the level of the riverbank? It is not only that the arresting beauty of this area, nestled between Arches National Park and Canyonlands National Park along the Colorado River in eastern Utah, draws a visitor's attention away from a rather nondescript, albeit large, pile of mining debris. It is also that the pile, for all its mass, is dwarfed by the grand scale of the environs—a mere ankle on the huge but commonplace Poison Spider Mesa that rises nearly a thousand feet above the pile and extends for miles in each direction. The exposed strata on the sides of the mesa overlooking the water display a record of the area in geologic time, written with the insistent and enduring erosive power of the Colorado River. The pile, too, represents a history of the area, on the more diminutive time scale of human generations, illustrating both the fast-paced physical change brought by industrial mining and milling operations, and the shifting priorities and demands of the city and the nation.

What is now termed the Moab Site was once the site of the Uranium Reduction Company's mill, which processed uranium ore from the surrounding area. The United States' demand for uranium during the Cold War and the discovery of rich uranium deposits near Moab resulted in a classic American story of a boomtown. The mill was sold in 1962 to the Atlas Corporation, which owned the site and sporadically operated the mill until the company declared bankruptcy in 1998. In 1999, a trust was created to fund remediation of the site and PricewaterhouseCoopers was named as the custodian of the trust. In 2000, Congress passed the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 (Public Law 106-398, hereafter referred to as the Act), which transferred ownership of and responsibility for the site to the U.S. Department of Energy (DOE). The Moab Site thus joined over 100 other sites that DOE must remediate as part of the legacy of the Cold War.

The Act also required DOE to ask the National Academy of Sciences (NAS) to review DOE's plan for remediation of the Moab Site. The Act specifically directs DOE to ask the NAS to provide technical advice and recommendations to assist DOE in objectively evaluating costs, benefits, and risks associated with remediation alternatives for the Moab Site, including removal or treatment of radioactive or other hazardous materials at the site, ground water restoration, and long-term management of residual contaminants. The National Research Council, the chief operating arm of the NAS and the National Academy of Engineering, charged its Committee on Long-Term Institutional Management of DOE Legacy Waste Sites: Phase 2 with carrying out those tasks.

Historical Background on the Moab Area[21]

Native Americans belonging to Ute tribes lived in what is now called the Moab Valley until 1878 when, after a failed attempt in 1855, a Mormon settlement took hold. Before these settlements, the fifteen-mile long, three-mile wide valley was part of the northern route of the Old Spanish Trail—connecting Los Angeles and Santa Fe—locally following the path of what is now U.S. Highway 191 across the Colorado River (see Figure 2). The area's role as a provider of raw material for nuclear science began when it was discovered that carnotite, a red and yellow mineral found on the Colorado Plateau, contains radium. Radium mines in what are now Grand

[20] Most of the history of the Moab area is taken from various articles in the Utah History Encyclopedia, with additional details taken from the Reference [U.S. NRC 1999], in this report.
[21] See Figure 1 for a current-day map of the region, Figure 2 for a map of the Moab Site and its vicinity, and Figure 3 for an aerial photograph of the area with landmarks.

and San Juan counties provided ore to Marie and Pierre Curie, who earlier were the first to isolate the element. Radium was also provided for ill-conceived radium "cures" and for luminous paint used for clocks and watches. For the first half of the twentieth century, mining was a small but significant part of the Moab economy, which was dominated by ranching, farming, and fruit growing.

This changed with the dawning of the Atomic Age. After World War II, the U.S. Atomic Energy Commission (AEC) announced an effort to obtain uranium from within the United States. The AEC constructed federally owned mills, identified promising locations for prospectors, paid bonuses for new lodes of high-grade ore, guaranteed minimum prices, and helped with haulage. The uranium boom truly took hold in 1952 after Charlie Steen, a geologist from Texas, found high-grade ore in the Big Indian Wash of Lisbon Valley, southeast of Moab. Steen had been searching for two years in areas that others thought were barren of ore. In fact, he found some of the richest ore in the United States. Steen formed the Uranium Reduction Company and opened the nation's second largest uranium processing mill in 1956, the first designed to process the uranitite ore he found. The population of Moab soared from 1,275 in 1950 to 4,682 in 1960. In 1962 the mill was sold to the Atlas Corporation, in the same year that the AEC announced it had ample amounts of uranium and the buying program would be phased out over eight years. In 1970, uranium production in the area virtually stopped and, except for a small revival based on perceived demand for nuclear power plants in the mid-1970s, it has never really revived.

Other booms and busts have hit the area. Oil fields operated near Moab around the same time as the uranium boom. In 1963, the Texas Gulf Sulphur Company opened a potash mining plant in the area, and despite huge expansions and contractions in the local operations, potash is still produced by Moab Salt, Inc. near Moab. Today, tourism is the mainstay of the local economy, and the population of Moab, which is also now the county seat for Grand County, is once again rising. Tourists from around the world are attracted to the area for its natural beauty, exemplified by (but not limited to) adjacent Arches National Park, nearby Canyonlands National Park, and the magnificent gorges of the Colorado River and their grand portals into Moab Valley. The land now derives an economic value from its undisturbed state rather than from its mineral and fossil resources.

The Geological Setting at the Moab Site[22]

The Moab Site is physiographically located in the Colorado Plateau Province, and geologically located in the fold-and-fault belt of the Pennsylvanian Paradox basin. The Colorado River flows along the southeast side of the Moab Site. Geologic features of the area were influenced by Middle Pennsylvanian to Late Triassic salt tectonics, Middle Pennsylvanian to Late Cretaceous sedimentation, Tertiary folding and faulting, and Quaternary erosion and salt dissolution. With the uplift of the Colorado Plateau, the Colorado River eroded the sedimentary formations and formed deep canyons, slopes, and cliffs. The formations formed either cliffs or slopes according to their erosional resistance. After erosion cut down deep enough, ground water reached the upper parts of the underlying evaporite deposits and dissolved salt. The ensuing collapse created graben-valleys, such as the Moab Valley, that overlie the salt deposits. The Moab Site is at the northwest end of the Moab Valley. Consolidated sedimentary rocks exposed in the area range in age from Middle Pennsylvanian to Late Cretaceous. Unconsolidated deposits of sand, silt, gravel, and clay, which are products of the current erosional regime, overlie the bedrock formations in places. Thickness and distribution of the geologic units vary considerably in the area.

[22] With the exception of the streamflow data, this section is extracted from the Draft Preliminary Plan for Remediation [DOE 2001]. Some portions have been omitted, but essentially all of this section is quoted or adapted from that document.

The Moab Site is bordered on the north and west sides by bedrock units, and by the Colorado River on the southeast side. The ephemeral Moab Wash enters the site at the northwest corner and drains through the site into the Colorado River. The site is directly underlain by Quaternary alluvial deposits, which in turn overlie various bedrock units at depth depending on the structural configuration beneath the site. Two large faults are likely present beneath the site, including the northeast-dipping normal Moab fault and the southeast-dipping "arcuate" fault. The arcuate fault defines the northwest extent of the Moab salt valley [SMI 2001].

The Colorado River traverses the valley roughly north to south, connecting two bedrock portals. The nearest gauging station for assessing stream flow is upstream near Cisco, Utah. Figure 4 exhibits the entire data record for annual peak stream flow at the Cisco station.

Physical Description of the Moab Site and the Pile

The site is irregularly shaped and encompasses approximately 400 acres. A 130-acre uranium mill tailings pile, about 0.5 mile in diameter and averaging about 94 feet (ft) in height above the surface of the Colorado River terrace, is located on the site about 750 ft west of the Colorado River. The Moab Site is bordered on the north and southwest by steep sandstone cliffs. The Colorado River forms the southeastern boundary of the site. U.S. Highway 191 parallels the northern site boundary, and State Highway 279 parallels the southwestern boundary. The entrance to Arches National Park is located less than one mile northwest of the site across U.S. Highway 191; Canyonlands National Park is about 12 miles to the southwest. The Union Pacific Railroad traverses a small section of the site just west of State Highway 279, then enters a tunnel and emerges several miles to the southwest. Moab Wash runs northwest to southeast through the center of the site and joins with the Colorado River. The wash is an ephemeral stream that flows only after precipitation or during snowmelt. Figure 2 shows major site features. The map in Figure 2 was completed in 1983; the majority of on-site buildings have since been demolished and the on-site tailings were consolidated. However, contamination is still present in many areas of the site.

The pile consists of an outer compact embankment of coarse tailings, an inner impoundment of both coarse and fine tailings, and an interim cover of soils taken from the site outside the pile area. The pile has five embankments, or terraces, that were raised to their present elevation of 4,076 ft above mean sea level after a 1979 license renewal. Debris from dismantling the mill buildings and associated structures has been placed in an area at the southern toe of the pile and covered with contaminated soils and fill [USNRC 1999].

A geotechnical, geochemical, and hydrologic investigation of the tailings impoundment was conducted by Steffen Robertson and Kristen [SRK 2000] on behalf of the site Trustee. The results of the investigation indicated that the center of the tailings pile remains saturated. In order to dewater and consolidate the pile, vertical band drains, also called wicks, were installed to within approximately 10 feet of the bottom of the tailings on roughly 3 meter centers over most of the impoundment surface. The surface of the tailings was surcharged with impacted surface soils excavated from the mill site and materials from the regrading of the impoundment side slopes. This surcharging caused increased pore water pressure in the tailings that allows tailings water to flow up the band drains to the surface of the tailings for subsequent evaporation [SMI 2001].

Less surcharge was placed on the tailings than originally planned, resulting in slower consolidation rates and less water being brought to the surface of the impoundment than anticipated. To date, no as-built survey of the existing tailings surface configuration is available. Therefore, it is not known how much surcharging was placed on the tailings or how much water has been brought to the surface [SMI 2001]. No accurate estimate of the amount of water brought to the surface by the band drains has been made. The tailings water is ponded on the surface of the impoundment and is in communication with the band drains, decreasing the effectiveness of the band drains for dewatering [SMI 2001]. Dewatering continues today, though at a slower rate than previously.

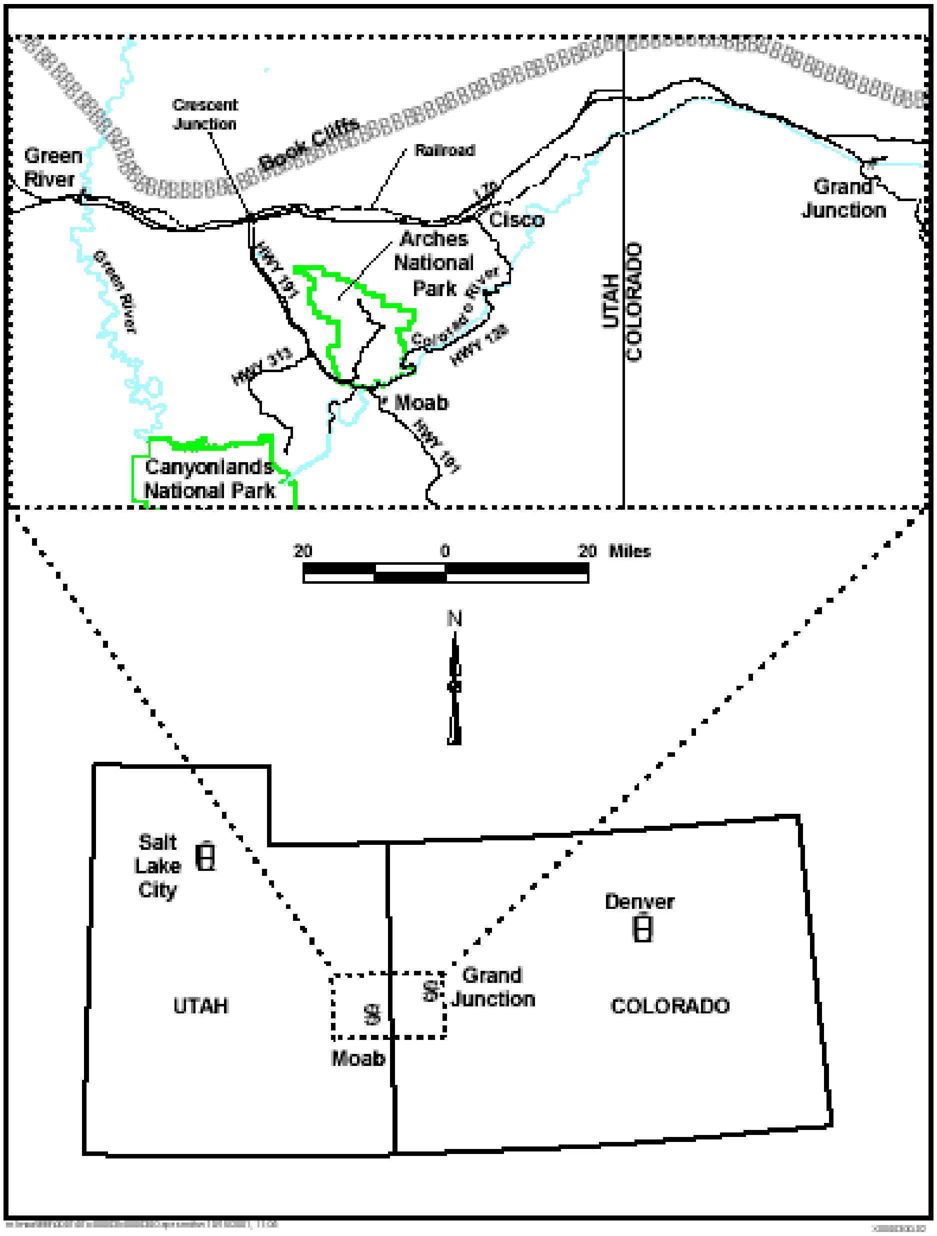

Figure 1. Current-day map locating Moab in the region (from [DOE 2001]).

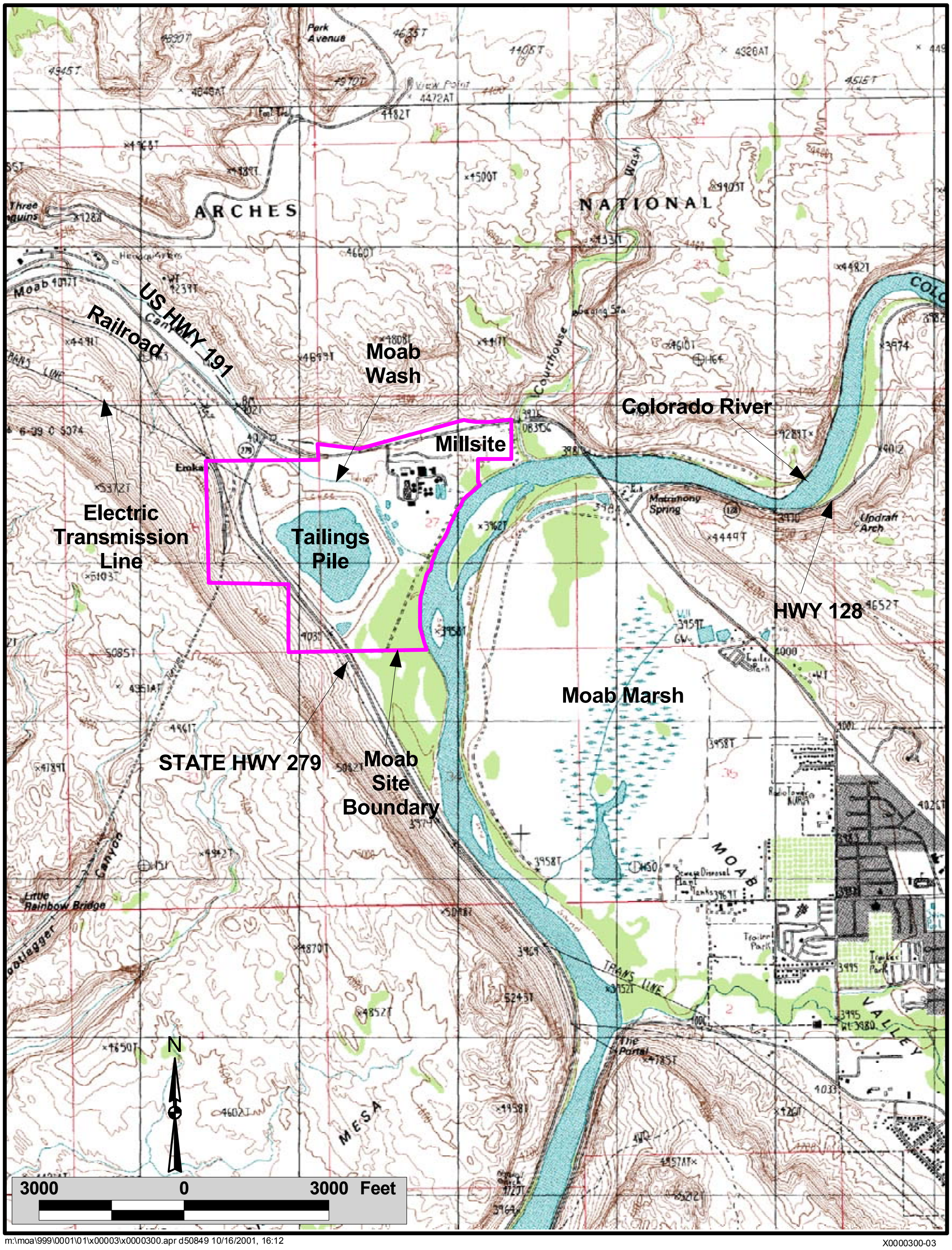

Figure 2. Current-day map showing the Moab Site and its vicinity (from [DOE 2001]).

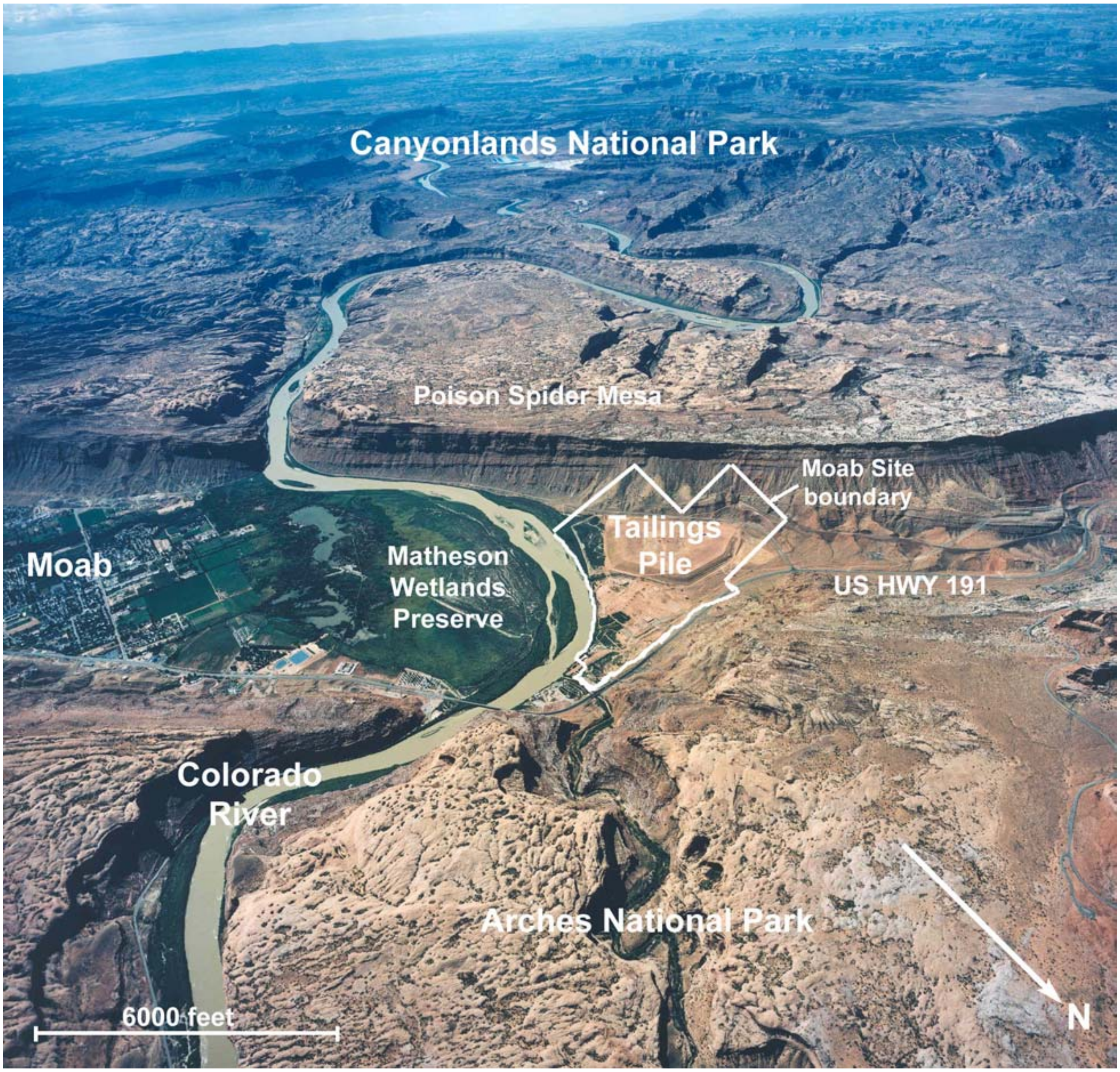

Figure 3. Oblique aerial photograph (courtesy of DOE). Markings in white were added by the committee. Directions, distances, and boundaries are approximate, and the distance scale corresponds roughly to the location of the pile in the picture.

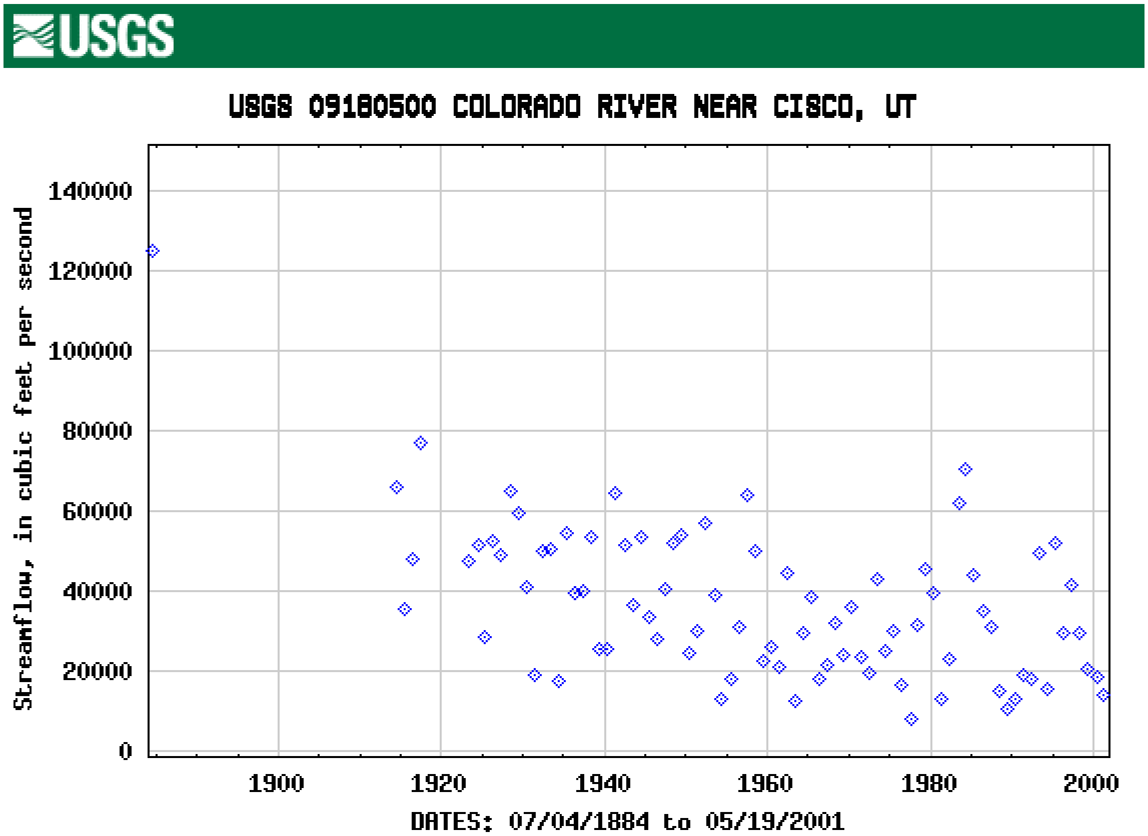

Figure 4. Annual peak streamflow for the Colorado River near Cisco, Utah [USGS 2002].

APPENDIX B

Committee Roster
Committee Member Biographies
List of Reviewers
Agenda of the January 14-15, 2002, Meeting in Moab, Utah
List of People who Provided Input

COMMITTEE ON LONG-TERM INSTITUTIONAL MANAGEMENT OF DOE LEGACY WASTE SITES: PHASE 2

KAI N. LEE, *Chair*, Williams College, Williamstown, Massachusetts
CHRIS G. WHIPPLE, *Vice-Chair*, ENVIRON International Corporation, Emeryville, California
JOHN S. APPLEGATE, Indiana University School of Law, Bloomington
SUSAN L. BRANTLEY, Pennsylvania State University, University Park
THURE E. CERLING, University of Utah, Salt Lake City
ALLEN G. CROFF, Oak Ridge National Laboratory, Tennessee
PATRICIA J. CULLIGAN, Massachusetts Institute of Technology, Cambridge
STEVEN N. HANDEL, Rutgers, The State University of New Jersey, New Brunswick
ROBERT J. HUGGETT, Michigan State University, East Lansing
TODD R. LA PORTE, University of California, Berkeley
P. SURESH RAO, Purdue University, West Lafayette, Indiana
ALLAN C.B. RICHARDSON, U.S. Environmental Protection Agency (retired), Bethesda, Maryland
MILTON RUSSELL, University of Tennessee, Knoxville
MICHELE STRAUBE, CommUnity Reslolution, Inc., Salt Lake City, Utah

Staff

MICAH D. LOWENTHAL, Staff Officer
DARLA J. THOMPSON, Research Assistant
LAURA D. LLANOS, Senior Project Assistant

COMMITTEE ON LONG-TERM INSTITUTIONAL MANAGEMENT OF DOE LEGACY WASTE SITES: PHASE 2

BIOGRAPHIES

CHAIR
Kai N. Lee is Rosenburg Professor of Environmental Studies and former director of the Center for Environmental Studies at Williams College. He previously taught political science and environmental studies at the University of Washington and has been a visiting professor, lecturer, or research fellow at the Kyoto Institute of Economic Research, Kyoto University, Stanford University, the University of California at Berkeley, Trent University, the University of Wisconsin, Memorial University of Newfoundland, and an on-line education program at the Western Behavioral Sciences Institute. He has served on nine committees of the National Research Council related to environmental issues. Dr. Lee earned his A.B. in experimental physics from Columbia and his Ph.D. in experimental physics from Princeton. In 1971 he was awarded a research training fellowship by the Social Science Research Council, after which he began his professional career in political science and environmental studies.

VICE CHAIR
Chris G. Whipple is a principal in ENVIRON International Corporation in Emeryville, California, which provides consulting services mainly to private industry. His professional interests are in risk assessment, and he has consulted widely in this field for private clients and government agencies. Prior to joining ENVIRON, he worked at ICF Kaiser Engineers and the Electric Power Research Institute. He served as member and chair of several National Research Council committees. Dr. Whipple holds a Ph.D. and M.S. in engineering science from the California Institute of Technology and a B.S. in engineering science from Purdue University. Dr. Whipple is a member of the National Academy of Engineering.

John S. Applegate is Walter W. Foskett Professor of Law at the Indiana University School of Law--Bloomington. He teaches and writes about environmental law, regulation of hazardous substances, risk, environmental remediation, and the Department of Energy. Mr. Applegate co-chaired the Long-Term Stewardship and Accelerated Cleanup subcommittees of the Department of Energy's Environmental Management Advisory Board. He was previously the James B. Helmer, Jr., Professor of Law at the University of Cincinnati College of Law and chaired the Fernald Citizens Advisory Board and has been a visiting professor at Vanderbilt University Law School, a judicial clerk to the United States Court of Appeals for the Federal Circuit, and an attorney in private practice. He is the author or co-author of over 20 articles and one book on risk and environmental law. Mr. Applegate received a B.A. in English from Haverford College and a J.D. from Harvard Law School.

Susan L. Brantley is professor of geosciences and director of the Center for Environmental Chemistry and Geochemistry at Pennsylvania State University. Dr. Brantley’s research focuses on chemical processes associated with the circulation of aqueous fluids in shallow hydrogeologic settings and deep in the earth's crust. Her research incorporates field and laboratory work, and theoretical modeling of observations to better understand what controls the chemistry of natural water and how water interacts with the rocks through which it flows. Dr. Brantley was a Fulbright Scholar and has been a visiting scientist at both the U.S. Geological Survey and Stanford University. She has received both the NSF Presidential Young Investigator Award and the David and Lucile Packard Fellowship. She has previously served on two committees for the National Research Council. Dr. Brantley received her B.A. in chemistry and received her M.A., and a Ph.D., both in geological and geophysical sciences, all from Princeton University.

Thure E. Cerling is professor of geology and geophysics at the University of Utah. His research interests focus on the use of isotopes as hydrologic tracers, geology of Old World paleoanthropologic sites, soils as climatological indicators, and environmental geochemistry (contaminant migration in ground water, rivers, and soils), among others. Dr. Cerling has been a visiting professor or fellow at the Scripps Institution of Oceanography; Yale University; the Université de Lausanne; Hebrew University, Israel; and the California Institute of Technology. He is a fellow of the Geological Society of America and has served the National Research Council’s Board on Earth Sciences and Resources and as a committee member on several studies. Dr. Cerling received his B.S. in geology and chemistry and his M.S. in geology, both from Iowa State University, and received his Ph.D. in geology from the University of California at Berkeley. Dr. Cerling is a member of the National Academy of Sciences.

Allen G. Croff is manager of Environmental Quality R&D Program Development in the Biological and Environmental Sciences Directorate at Oak Ridge National Laboratory (ORNL). Prior to this position he was associate director of the Chemical Technology Division at ORNL. His area of focus is initiation of research and development involving waste management and nuclear fuel cycles. Since joining ORNL in 1974, he has been involved in numerous technical studies that have focused on waste management and nuclear fuel cycles. He has served on several National Research Council committees, including the Committee on Remediation of Buried and Tank Wastes, which produced the Phase 1 report on long-term institutional management of DOE sites, in 2000. Mr. Croff holds a B.S. in chemical engineering from Michigan State University, a Nuclear Engineer degree from the Massachusetts Institute of Technology, and an M.B.A. from the University of Tennessee.

Patricia J. Culligan is an associate professor of civil and environmental engineering at the Massachusetts Institute of Technology. Dr. Culligan's research interests lie in the field of geo-environmental engineering and focus primarily on the experimental and numerical modeling of flow and contaminant transport processes in geologic systems. Her current research addresses the effectiveness of in situ remediation strategies for the cleanup of waste sites. In addition, she has worked in the design of land-based disposal cells. Dr. Culligan has received numerous awards including the Arthur C. Smith Award for Undergraduate Service, and the NSF CAREER Award. She is also the author or co-author of over 50 journal articles, book chapters, and refereed conference papers. Dr. Culligan received her B.Sc. degree from the University of Leeds, England, and her M.Phil. and Ph.D., both from Cambridge University, England.

Steven N. Handel, professor of ecology and evolution at Rutgers, The State University of New Jersey, New Brunswick, studies the population biology of native plants in many habitats. He is currently director of the Center for Urban Restoration Ecology. Prior to joining the faculty at Rutgers, he was associate professor of biology and director of the Marsh Botanic Garden at Yale University, and also taught at the Rocky Mountain Biological Laboratory, Mountain Lake Station, and the University of South Carolina. He is a fellow of the American Association for the Advancement of Science, a fellow of the Australian Institute of Biology, an Aldo Leopold Fellow of the Ecological Society of America, and an associate editor of the journal, Restoration Ecology. Dr. Handel previously served as president of the Torrey Botanical Society and as a member of the board of directors of the Society for Ecological Restoration. Dr. Handel received his B.A. in biological sciences from Columbia College and received his M.S. and his Ph.D. from Cornell University in ecology and evolution.

Robert J. Huggett is vice president for Research and Graduate Studies at Michigan State University (MSU). Before joining MSU in June 1997, he was assistant administrator for Research and Development at the U.S. Environmental Protection Agency and led committees on environmental issues within the White House Office of Science and Technology Policy. He is professor emeritus at the College of William and Mary, where he was a faculty member for 20 years. During those years he also served as chair of Environmental Science in the School of Marine Science and head of the Division of Chemistry and Toxicology. Dr. Huggett has studied the fate and effects of hazardous chemicals in aquatic environments, publishing more than 80 articles. He has served on several committees of the National Research Council. Dr. Huggett attended the College of William and Mary and then earned a M.S. in marine chemistry from the Scripps Institute of Oceanography at the University of California at San Diego and a Ph.D. in marine science at William and Mary.

Todd R. La Porte is professor of political science at the University of California at Berkeley. His fields of specialization are theories of public organization and administration; and science, technology, and politics. Dr. La Porte teaches courses on public organization theory, administrative behavior, and technology and politics. His current research focuses on high-reliability organizations and the relationship of large-scale technical systems to political legitimacy. Dr. La Porte chaired the Secretary of Energy Advisory Board's Task Force on Radioactive Waste Management and has served on several committees of the National Research Council. He was elected to the National Academy of Public Administration in 1985, but is no longer an active member. Dr. La Porte received his B.A. in social sciences and mathematics from the University of Dubuque and received his M.A. and his Ph.D., both in political science from Stanford University.

P. Suresh C. Rao is the Lee A. Rieth Chair & Distinguished Professor in the School of Civil Engineering at Purdue University and he holds a joint appointment in the Agronomy Department in the School of Agriculture. Prior to arriving at Purdue, Dr. Rao was on the faculty at the University of Florida for 24 years where he now holds an appointment as an emeritus graduate research professor. Dr. Rao teaches contaminant hydrology and remediation engineering. His research has involved development of innovative technologies for characterization of hazardous waste sites, and for enhanced remediation of contaminated soils and aquifers. He has served on several committees of the National Research Council. Dr. Rao has received several awards including the Environmental Quality Research Award and the EPA Scientific & Technology Achievement Award. He is a fellow of the Soil Science Society and the American Society of Agronomy. Dr. Rao received his B.Sc. in Agriculture from the A.P. Agriculture University in India, his M.S. in soil science from Colorado State University, and his Ph.D. in soil science from the University of Hawaii.

Allan C.B. Richardson is an independent consultant on issues related to cleanups involving radioactive contaminants. Prior to retiring in 1998, he was associate director for radiation policy in the U.S. Environmental Protection Agency's Office of Radiation and Indoor Air. Mr. Richardson joined the EPA when it was formed in 1970 and led or played a key role in the development of most of the Agency's standards for radiation. Prior to joining the EPA, he was a nuclear physicist at the National Bureau of Standards. Mr. Richardson has served as a committee member for the International Commission on Radiological Protection. He has consulted for international organizations, such as the International Atomic Energy Agency, and has served as advisor to the peoples of Bikini, Enewetak, and Rongelap, and the Rocky Flats Citizens Advisory Board. He received several awards for distinguished service in EPA. He is the author of many publications in professional journals and technical reports. Mr. Richardson received his B.S. in chemistry from the College of William and Mary and his M.S. in molecular physics from the University of Maryland.

Milton Russell is a senior fellow and was founding director of the Joint Institute for Energy and Environment; he is also professor emeritus of economics at the University of Tennessee. His current research focuses on analysis and policy direction for managing the environmental legacy of Department of Energy facilities. Dr. Russell has taught at several universities in the United States and abroad. He served as senior staff economist for the President's Council of Economic Advisers, and later as director of the Center for Energy Policy Research at Resources for the Future. Dr. Russell served as assistant administrator of the U.S. Environmental Protection Agency, directing its policy, planning, regulatory development, and evaluation functions. He has served on several committees of the National Research Council, was a member of the Secretary of Energy Advisory Board, and has been elected a fellow of the Society for Risk Analysis. He is currently chair of the Westinghouse Savannah River Site Environmental Advisory Committee. Dr. Russell received his B.A. from the Texas College of Arts and Industries and his M.A. and his Ph.D., both in economics from the University of Oklahoma.

Michele Straube is co-founder of CommUnity Resolution, Inc. which provides mediation, facilitation, and environmental-policy consulting services to local, state, and federal governments focusing on RCRA and Superfund issues. She is also adjunct professor at the University of Utah College of Law. Much of her current work involves designing and implementing collaborative processes to involve communities and citizens in government and corporate environmental decision making. Ms. Straube previously served as director of the State Superfund Network, senior attorney at the Environmental Law Institute, an attorney in private practice, director of the Alaska Consumer Advocacy Program, and an enforcement attorney with the Pennsylvania Department of Environmental Resources. Ms. Straube received a B.A. in linguistics and German from Rice University, and she received a J.D. from the Franklin Pierce Law Center in Concord, New Hampshire.

LIST OF REVIEWERS

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Mary Jo Baedecker, U.S. Geological Survey
Robert Bernero, U.S. Nuclear Regulatory Commission (retired)
Gail Charnley, Health Risk Strategies
Mary R. English, University of Tennessee
John C. Fountain, North Carolina State University
James R. Karr, University of Washington
Howard C. Kunreuther, University of Pennsylvania
Jonathan Price, Nevada Bureau of Mines and Geology and University of Nevada
Charles D. Shackelford, Colorado State University
Leon T. Silver, California Institute of Technology (retired)

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by George M. Hornberger of the University of Virginia. Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with NRC procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

MEETING OF
THE COMMITTEE ON LONG-TERM INSTITUTIONAL MANAGEMENT
OF DOE LEGACY WASTE SITES: PHASE 2
JANUARY 14-16, 2002
MOAB, UTAH

List of Presentations

Update on long-term-stewardship (LTS) planning and organization at DOE headquarters, David Geiser, DOE/EM-51, (by telephone)

DOE's Long-Term Surveillance and Maintenance Program and long-term stewardship, Art Kleinrath, DOE/GJO

Experience with managing moved piles, Art Kleinrath, DOE Grand Junction Office (DOE-GJO)

Experience remediating mill tailings piles (Title I), Russell Edge, DOE Albuquerque Office (DOE-AL)

Tour of the Atlas mill tailings pile, DOE/GJO

DOE Draft plan for remediating Moab Site, Ray Plieness and Moab Project Team, DOE/GJO

Views of the State of Utah, Dianne Nielson, Utah Department of Environmental Quality (UDEQ)

Ground Water (Panel)
GW studies by ORNL, Frank Gardner, Oak Ridge National Laboratory (retired)
GW studies by Shepherd Miller, Toby Wright, Shepherd-Miller, Loren Morton, Utah Division of Radiation Control, Pete Penoyer, U.S. National Park Service

Ecological and Human Health Impacts (Panel)
Studies of contaminant effects on larval fish, Ann Allert, U.S. Geological Survey, Bruce Waddell, U.S. Fish and Wildlife Service (U.S. FWS)
Human health and environmental impacts of management options, Mike Fliegel and Mike Layton, U.S. Nuclear Regulatory Commission (U.S. NRC)

Cost estimates, Russell Edge, DOE-AL, Don Metzler, DOE-GJO

Comments from DOE, Grand Junction, Donna Bergman-Tabbert, DOE-GJO

Regulatory Issues (Panel)
State of Utah perspectives and possible future regulation, Bill Sinclair, Utah Department of Environmental Quality, Loren Morton, Utah Div of Rad Control
Existing regulations and standards, Mike Fliegel, U.S. NRC
The Endangered Species Act, Yvette Converse, U.S. FWS
UMTRCA Title 1, Richard Graham, U.S. Environmental Protection Agency, Region 8

Perspectives on Tailings Management (Panel)

Kimberly Schappert, County Commissioner, William Hedden, Grand Canyon Trust, Utah, Mark Buehler, Los Angeles Metropolitan Water District

Speakers at Public Session held on January 15, 2002 at 7:00 p.m.[*]

Jim Matheson
Ron Hochstein
Greg Hahn
Bob Southards
Henry Maddux
Gary Hazen
Eleanor Bliss
Terry Tempest Williams
Lloyd Meehan
Mary Moran
Dave Bodner
Mark Beuhler
Sue Bellagambo
Ernie Lisenbee
Harvey Merrell
Bill Hedden

Written comments sent to the committee
Ivan Weber
Michael & Jean Binyon
Mark Beuhler
Alford Banta
Richard Christie
Loren Morton
Ron Hochstein
Greg Hahn

The committee also received input and information from the following government agencies and organizations.

Moab Tourism Bureau
Utah Department of Environmental Quality
U.S. Nuclear Regulatory Commission
U.S. Department of Energy (which also provided documents by contractors for Atlas and the reclamation trust)
U.S. National Park Service
U.S. Fish and Wildlife Service
U.S. Geological Survey

[*] The names listed represent the committee's record. The committee apologizes for any misspellings and omissions.