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ATTACHMENT C

RISK/COST ANALYSIS: A CASE SCENARIO IN THE DECOMMISSIONING OF A RADIOLOGICAL SITE

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Abstract

The explosion of environmental rules, regulations, and environmental liability assignments over the last dozen years has heightened corporate awareness of the need to characterize potential environmental liabilities, to develop a proper perspective on these liabilities and to take appropriate measures with respect to managing potential environmental remediation costs and liabilities.

Defacto environmental management considerations including standard engineering design and costs to meet evolving regulatory criteria need to be expanded to encompass a broader decision framework explicitly including assessment of regulatory and legal options, contingent environmental risks and the benefits of proactive management of the environment. The use of a probabilistic framework for the assessment of the various design options, resulting consequence analysis, and the potential social and political responses to these possible options provides a dynamic approach that empowers decision makers with new insights into the underlying assumptions, their uncertainty, and the stability of the resulting predictions.

This paper, illustrating the application of such a probabilistic analysis framework to the multivariate risk analysis and alternative option cost analysis related to the decommissioning options of a licensed uranium recovery facility, provides an interesting and current case study of the methodology of such an approach. In addition, the paper provides a discussion of the organizational mode that is critical to the successful realization of such an effort (namely the creation of a project team providing the key legal, environmental, financial, engineering and scientific expertise and practical experience). The paper describes the formulation of the problem, the development of necessary data in the form of probability distribution and the results of the case study which describes the potential environmental liability in the form of (subjective) probability distribution of current (i.e. 1995) dollars. Specifically, the focus is on a comparison of the risk and costs for an on-site versus a relocation alternative.

The screening analyses of the risks of reclamation of the material on site versus removing it from the site was a multi-variant/net benefit analysies that assessed all the costs and benefits associated with a planned course of action and the potential alternative. The components of the analysis included site characterization, estimates of costs to achieve "reasonable assurance" of regulatory compliance, comparisons of reductions in radiation doses (e.g. workers, nearby homes, transport accidents), comparisons of costs from removal of soil, disposal of the waste and radiation surveys, comparisons of impacts on the surrounding plant and wildlife environment and the physical environment (noise and aesthetics) and socioeconomic impacts, and the disposal capacity on and off site. The risks from radiation were placed in the context of natural background radiation exposures, radon exposures and gamma exposures from the material at issue, indoor radon exposures, and collective and individual doses.

The radiation risks were compared to the nonradiation risks from the intervention alternatives under consideration. Nonradiation risks include those associated with transportation, treatment and disposal of wastes, the use of chemicals for decontamination, structure demolition, material handling and packaging, fire and explosions, and the operation of heavy equipment.

The potential radiological risks were estimated (radon risk probabilistically) and added to the nonradiological risks which resulted in a range of risks for the relocation alternative that were 5-15 times higher than on-site *in situ* reclamation.

In addition, conceptual cost estimates were developed for the on-site reclamation plan and for the relocation alternative. It was clear from preliminary estimates, that costs of relocation would significantly exceed those of inplace reclamation. As part of this process, reviews of completed, in progress and planned tailings reclamation programs were undertaken to determine the range of reclamation costs for similar plans. The cost estimates were subjected to a sensitivity analysis based on worst case critical design criteria, as well as a probabilistic, Monte Carlo sensitivity analysis of worst-case hypothetical events or reasonable worst-case and additional potential design requirements. These analyses showed that the facility's cost estimates were appropriate.

In seeking to obtain a positive net benefit, the disposal of radioactive waste off-site must be viewed in the context of all the benefits, risks and costs associated with remediation of the site and not looked at as an isolated action. Given this context, this paper will examine the components of such a multi-variant risk/cost analysis for this site and the two clean-up alternatives under consideration.

Background

In the late 1940s, a uranium mining boom occurred on the Colorado Plateau and, by 1956 over 600 producers were shipping ore from the area. As ore production exceeded milling capacity, the Atomic Energy Commission (AEC) encouraged private development of processing facilities.

In response to this encouragement, the Uranium Reduction Company constructed the Moab Uranium Mill in 1956 and began operation. Atlas Corporation purchased the mill in 1962 and formed Atlas Minerals Division to operate the facility. Between 1956 and 1984, the mill processed over 10.5 million tons of ore and deposited approximately that amount of tailings into the existing pile.

Throughout this period, the Atlas Mill was the major employer in Moab and Grand County and, at the peak of its operation the work force totalled 500 people. During the uranium boom, Moab was one of the wealthiest towns in that part of the country and the Atlas Mill played a key role in the creation of the infrastructure of today's Moab.

As the demand for uranium fell and depressed the uranium market, the Atlas Mill was put on standby in 1984. The domestic uranium market did not improve and the company shut down the mill in 1988.

Radiological Issues

The ore contained radioactive uranium which was removed in the milling process and shipped out to nuclear facilities for conversion to fuel. However, the ore also contained a series of radionuclides that are products of uranium which remain in the tailings pile and in wastes in and around the uranium mill. Atlas has begun the mill reclamation phase and is currently dismantling, decontaminating and salvaging or burying (in the tailings pile) the buildings, foundations and equipment. After completion of mill reclamation, the tailings pile reclamation phase will address the residual radioactivity in the tailings pile. The tailings pile must be remediated as the radioactivity in it can result in radiation exposures in the following ways:

- direct gamma radiation to those standing on top of the waste;
- wind can resuspend tailings dust and transport it off-site resulting in inhalation and ingestion of contaminated dust;
- radon gas can escape from the surface of the pile and be transported off-site resulting in inhalation of radon progeny (or daughters); and
- rainfall can permeate the tailings pile and seep into the soil and groundwater beneath.

Proposed Reclamation Plan

The reclamation plan proposed for the tailings pile and surrounding area is designed to mitigate foreseeable potential hazards and to provide safe reclamation with reasonable assurance for 200 years, and to the extent practicable, for 1,000 years. Contaminated materials and soils on the site will be placed in the 130 acre tailings area. The site will be recontoured, capped with both clay and sandy soil layer and then covered with rock armoring.

- The clay layer will prevent penetration of precipitation into tailings and the (uncontaminated) runoff will be directed off the pile via contoured channels. This will reduce seepage into groundwater from the tailings pile.

- The clay layer and other cover materials will prevent the resuspension of contaminated dust by the wind and eliminate the inhalation and ingestion of dust as potential exposure pathways.
- The clay layer and cover will reduce the escape of radon gas from the pile below the regulatory standard of 20 pCi $m^{-2} s^{-1}$ and reduce the potential exposures to radon daughters to a rate that is considered presumptively safe (provides an "ample margin of safety").
- Regrading of the tailings embankments will reduce the slope to meet design specifications.
- The tailings pile will be dewatered by pumping from wells drilled at several locations to stabilize the pile and reduce seepage into groundwater.
- Rock armor will stabilize the clay cover and reduce penetration by wildlife.
- The site will be fenced, monitored and inspected.

Review Process

Commencing in 1988, the existing and approved plan for the on-site reclamation of the Moab tailings pile has been undergoing revisions to incorporate new NRC guidelines and criteria. NRC had previously reviewed and approved Atlas' plan for on-site reclamation in 1982. The most recent review (i.e. 1996) by NRC addresses Atlas' revisions (requested by NRC) to the approved reclamation plan and requests additional information pursuant to NRC's 1994 environmental impact statement (EIS) proceeding which followed from NRC's reversal of a Finding of No Significant Impact (FONSI) and environmental assessment (EA) related to the proposed license revisions.

As part of the process of reviewing reclamation alternatives, conceptual cost estimates were developed in 1993 by Atlas for the revised on-site reclamation plan, as well as for the NRC requested alternative reclamation concept in which tailings would be relocated to a new site some 18 miles from the existing locations. These 1993 cost estimates, indicated that on-site reclamation could range from $13 to $16 million, while off-site reclamation could range from $94 to $114 million. These costs were provided to NRC as reasonable (lower limits) appropriate for purposes of comparison of the alternatives as defined at that time. Based on these preliminary estimates, it was evident that the financial implications of relocation would significantly exceed those of on-site reclamation and would far exceed Atlas' capacity to fund. Thus, the relocation option would likely result in Atlas' bankruptcy and transfer of significant liability to other potentially responsible parties, possibly including the United States government.

As noted, the 1996 NRC evaluation resulted from questions raised during the response period following NRC's publication of the FONSI, and its subsequent withdrawal. An NRC mandated EIS and accompanying technical evaluation report (TER) has required further reconsideration of site reclamation through relocation to the alternate potential site as well as the resolution of a number of outstanding technical issues related to on-site reclamation.

The technical issues that have the potential to affect the on-site estimate primarily relate to final engineering design for physical stability under seismic events and long-term surface stability requirements to ensure protection against physical erosion and to minimize groundwater and air pathway impacts. These issues have been, and continue to be under investigation and technical development as part of the ongoing EIS/TER process. The issues that can dramatically affect the cost of off-site reclamation are primarily related to excavation and material handling, hauling, excavation, transport and placement of the fine tailings (slimes).

Overall, the issues identified as needing a critical review included radiation dose estimates, engineering and cost impacts and legal/regulatory issues.

Legal and Policy Issues

The Atomic Energy Act (AEA) as Amended by the Uranium Mill Tailings Radiation Control Act (UMTRCA), governs reclamation of uranium mill tailings piles such as the Atlas Moab pile. EPA and NRC have developed extensive regulatory programs pursuant to UMTRCA to address the potential radiological *and nonradiological* hazards associated with mill tailings. Given the long time frames involved (200 to 1,000 years) the regulatory criteria set forth in 10 CFR Part 40, Appendix A of NRC's regulations must be satisfied with "reasonable assurance". Thus in addressing reclamation alternatives the alternative recommended must provide such "reasonable assurance" and the analyses performed must adequately consider the environmental issues relevant to each alternative, even though not necessarily choosing the "environmentally preferred" alternative. UMTRCA also requires a reasonable balancing of risks with costs of controls.

It is within this statutory/regulatory framework and the framework of recommendations of expert, independent organizations regarding "optimization" of benefits versus costs (i.e. do more good than harm) that analyses of reclamation alternatives must proceed.

The context for this analysis begins with reference to the system of radiological protection recommended by the International Commission on Radiological Protection (ICRP) which is based on the principle that "the proposed intervention should do more good than harm, i.e. the reduction in detriment resulting from the reduction in dose should be sufficient to justify the harm and the costs, including social costs, of the intervention." The "net benefit" must be considered in determining the best alternative for remediating a site. The Health Physics Society (HPS) describes this type of analysis as a means of "optimizing" risk. HPS explains that "the application of the 'ALARA' (As Low As a Reasonably Achievable) or the optimization principle is not a mechanism for assigning a value to human life, but is a process for optimizing the use of limited resources for improving life expectancy and health benefits when all risks are considered

The Nuclear Regulatory Commission (NRC) acknowledges "there is a point at which the net risk to future populations from residual radioactivity is lower than the risk from remedial action. In other words, the clean-up may do more harm than good." Another factor weighed into the consideration is potential public concern over the risks. HPS cautions, though, that "the amounts spent specifically to achieve health benefits should be in the same range as is acceptable for any other health protections program that is undertaken voluntarily by the public. Expenditures for other categories of benefits, e.g. aesthetics, public goodwill, and a proper evaluation, etc. should be separately identified and justified.

The screening risk analyses involved here considered recommended exposure levels for intervention by expert radiation protection organizations, existing exposure scenarios versus future scenarios, and the overall integrated waste management system. Probabilistic assessments of the risk consider long time frames, the nature of the potential risk, and the best estimates of risk.

Is there a reasonable alternative?

It should be noted that wherever reclamation is to be undertaken, the criteria to be met are the same.

As noted, it has been suggested that a conceptual alternative for the final reclamation of the Atlas tailings pile near Moab is relocation of the contaminated materials to an appropriate alternate site. Such a site has been identified approximately 18 miles northwest of the existing site in an area known as the Klondike Flat (2.5 miles from the Moab Canyon Lands airport). Ground surfaces on the site slope up steeply to the north, and are relatively flat to the south, east and west. The site is underlain by Mancos Shale consisting primarily of marine shale and some marine and non-marine sandstone units. The primary components and activities associated with reclamation to the off-site location as developed by Smith Environmental include:

- construction of new rail load-out facilities at existing site, rail unloading facilities at the alternate site, 3.5 miles of rail siding and improvements on 14 miles of the existing main line;
- excavation and loading of 7.8 million cubic yards (10.5 or more million tons) of tailings; and
- transport of tailings by rail to the alternate site.

During evaluation of the original (late 1970s) reclamation plan, Atlas and NRC considered the option of transporting the tailings to an alternate site. Both agreed that there was no demonstrable incremental public health or environmental benefit in spite of the greatly increased cost of tailings relocation. In addition, the relocation options directly conflict with NRC's stated policy which is to avoid a proliferation of regulated sites. Moving the tailings could create two sites that would need to be reclaimed, secured and monitored.

Of the 19 Title II sites where reclamation plans have been approved, there has been only one site (Edgemont, SD) where relocation of tailings was proposed by the licensee and that was done voluntarily by the Tennessee Valley Authority.

Multi-variant Risk Analysis

The potential radiological impacts on workers and members of the public from two reclamation options were estimated using accepted dose and risk models. The magnitude of predicted impacts of on-site reclamation were clearly lower in every category, even considering all foreseeable delays, when compared to corresponding impacts from alternate site reclamation.

The relative impacts of the two alternatives were evaluated for a range of assumptions regarding the time necessary to reclaim the tailings *in situ* or at an alternative site. Once the tailings have been reclaimed in accordance with EPA/NRC longevity (200-1,000 years) and radon flux criterion of 20 pCi $m^{-2} s^{-1}$, the tailings are presumptively safe with an "ample margin of safety". Therefore, the relative, or differential risks will continue to accrue for either alternative from present until the tailings have been reclaimed.

In the comparative analysis of the potential risks from reclaiming the Moab tailings *in situ* or by relocation, estimates were developed of potential societal (i.e. population) risks arising from radiation doses to the public and to workers as well as nonradiological actuarial risks to workers arising from potential construction and transportation accidents from the reclamation activities.

For comparative purposes, the multi-variant analysis added the potential stochastic radiation risk (to the population and workers) and the actuarial risks from construction and transportation (to workers). In doing this, it should be acknowledged, that at the calculated level of radiation dose, the uncertainty about the associated risks includes the possibility that the risks could actually be zero. This is in contrast to the actuarial risks from construction and transportation accidents where experience indicates that such risks are indeed likely to occur.

Table 1 shows a summary of the calculated risks to the population and to workers. To consider overall risks and costs the various types of risks must be added. Before adding the population (stochastic radiation) risk of cancer mortality to the risk of mortality from construction and transportation, it is necessary to convert the annual population risk (fatalities per year) to lifetime risks by multiplying by 70 years, the assumed (nominal) lifetime of the exposed population. The results are tabulated below. In addition to the on-site reclamation option and the relocation option, risks for the "no action" option are also presented. For present purposes; the risk for the "no action" option were calculated by assuming that the interim (current) situation continues for 30 years.

From the risk perspective, it is evident that overall the relocation scenario carries about five times the risk of on site reclamation and is roughly comparable on a risk basis to the no action alternative.

Estimates of dose and risk impacts described in this report are inherently uncertain. The uncertainty is attributable to many factors such as measurement inaccuracy, and temporal and spatial variability in environmental parameters and human behaviour.

To illustrate the significance of the uncertainty in predicted values of impacts, estimates of radiation dose to the nearest residents attributable to radon and dust emissions from the tailings pile were made using a probabilistic model. Dose calculations were made using environmental pathways algorithms embedded in a computer spreadsheet and Crystal Ball® which facilitates the repeated calculation (Monte Carlo

Table 1
COMPARISON OF TOTAL RISK

		On-Site	Relocation	Do Nothing (Interim)
Population cancer risk	low high	0.06 0.15	0.31 0.66	0.44
Cancer risk to workers		0.015	0.16	0
Risk of fatality from construction accident		0.006	0.09	0
Risk of fatality from transportation accidents		0.03	0.046	0
Total risk of fatality	low high	0.11 0.2	0.6 1.0	0.44

analysis) of the spreadsheet, with new values randomly selected for each input variable on each trial. The output, in this case dose, may be interpreted as a probability distribution which quantitatively represents the uncertainty (interpreted as subjective probability) associated with the calculation.

The mean dose to the maximum individual during the Interim Phase was predicted to be 38 mrem/y (standard deviation of 21 mrem/y) and the 95th percentile on dose (78 mrem/y) was approximately 2.1 times the mean dose. The mean dose to the maximum individual during post-reclamation was predicted to be considerably less at 3.8 mrem/y (standard deviation of 2.1 mrem/y) and the 95th percentile on dose (7.8 mrem/y) was also approximately 2.1 times the mean dose.

Costs of Reclamation

Preliminary cost estimates also were developed for both reclamation options. The 1993 estimate of the cost for on site reclamation was in the range of $13 - $16 million compared to costs of $94 - $114 million for the relocation alternative. Thus, based on preliminary cost estimates, costs for relocation exceed those for on site reclamation by between $80 million to $100 million. Confidence in the magnitude of this difference is critical to any net benefit analysis.

To test these estimates, a review of the engineering designs and cost considerations for both *in situ* and relocation options was performed. This assessment was performed to capture uncertainties in both cost and schedule, and included review of:

- completeness and state of design considerations;
- completeness of estimates and confirmation of rates;
- identification of potentially critical omissions or potential fatal flaws; and
- statistical analysis of sensitivity assessment of estimates.

Major uncertainties associated with this assessment include specific timing of events resulting from non-engineering factors and the consequent impact of inflation, sector specific constraints or other economic related effects that may result from assumptions about performance of the work at various times in the project life cycle.

Comparative Reviews

A review of completed, in progress, and planned uranium tailings reclamation programs was undertaken to ascertain the range of reclamation costs for similar programs. This review confirms that the Atlas estimates for on-site reclamation are reasonable when compared to other Title II site operations.

The results of the review show that for comparable Title II sites the total estimated cost of on-site reclamation plans range from $0.65/ton to 4.45/ton. When considered from a perspective of similar sized sites, it can be seen that the sites with similar surface area have an average cost of $2.49/ton, while sites with similar tailings volume have an average cost of $2.01/ton. From the information reported, a comparison of decommissioning costs related only to the reclamation of the tailings proper at these sites indicates a maximum range of $0.34/ton to $2.55/ton. When comparing the tailings reclamation costs at sites with similar surface areas, an average cost of $1.48/ton results as compared to sites with similar volumes where an average cost of $1.13/ton is reported.

Sensitivity Analysis

In an attempt to better quantify uncertainties in costing assumptions a probabilistic Monte Carlo analysis of 5,000 trials was performed for the alternatives. In this analysis, input parameters (e.g. unit costs for haulage, interest rates, labor rates, etc.) were assigned a range of values rather than single (point estimate) value. These ranges were input into the costing model in the form of probability distributions, and a distribution of possible costs for reclamation was estimated. The resulting probabilistic (worst case) analysis for reclamation of Moab tailings indicates a potential range of costs at the lower 5th and upper 95th percentile of $1.62/ton and $2.43/ton with a mean of $1.91/ton (see Figure 1).

The 1993 cost estimates showed that a significant increase of reclamation costs would be incurred if off-site reclamation to an alternate site was to be undertaken. For comparison purposes, information provided by DOE on costs of off-site reclamation was reviewed and analysed in the same manner as previously illustrated for on-site reclamation. The results of this review show that for sites having similar off-site reclamation requirements, in comparison to the alternate Moab site, reclamation costs range from $17.33/cubic yard to $34.74/cubic

yard and have an average cost of $22.45/cubic yard. By comparison to these costs, the Atlas 1993 relocation estimates were on the low side and ranged from $11.92/cubic yard to $14.36/cubic yard with an average of $13.14/cubic yard.

As was done for the cost of on-site reclamation estimates, uncertainty analyses were undertaken. These analysis reflected additional uncertainties over and above those considered in the base case, and in particular attempted to reflect the cost uncertainty associated with materials handing of slimes, excavation, and seismicity. The results of these analysis show an average worst case cost in 1995 dollars of $19.93/cubic yard with a range from $15.38/cubic yard to $24.49/cubic yard for the probabilistic analysis. In either case, the analyses indicated that Atlas estimates for relocation are at the low end of actual cost for similar sized tailings piles.

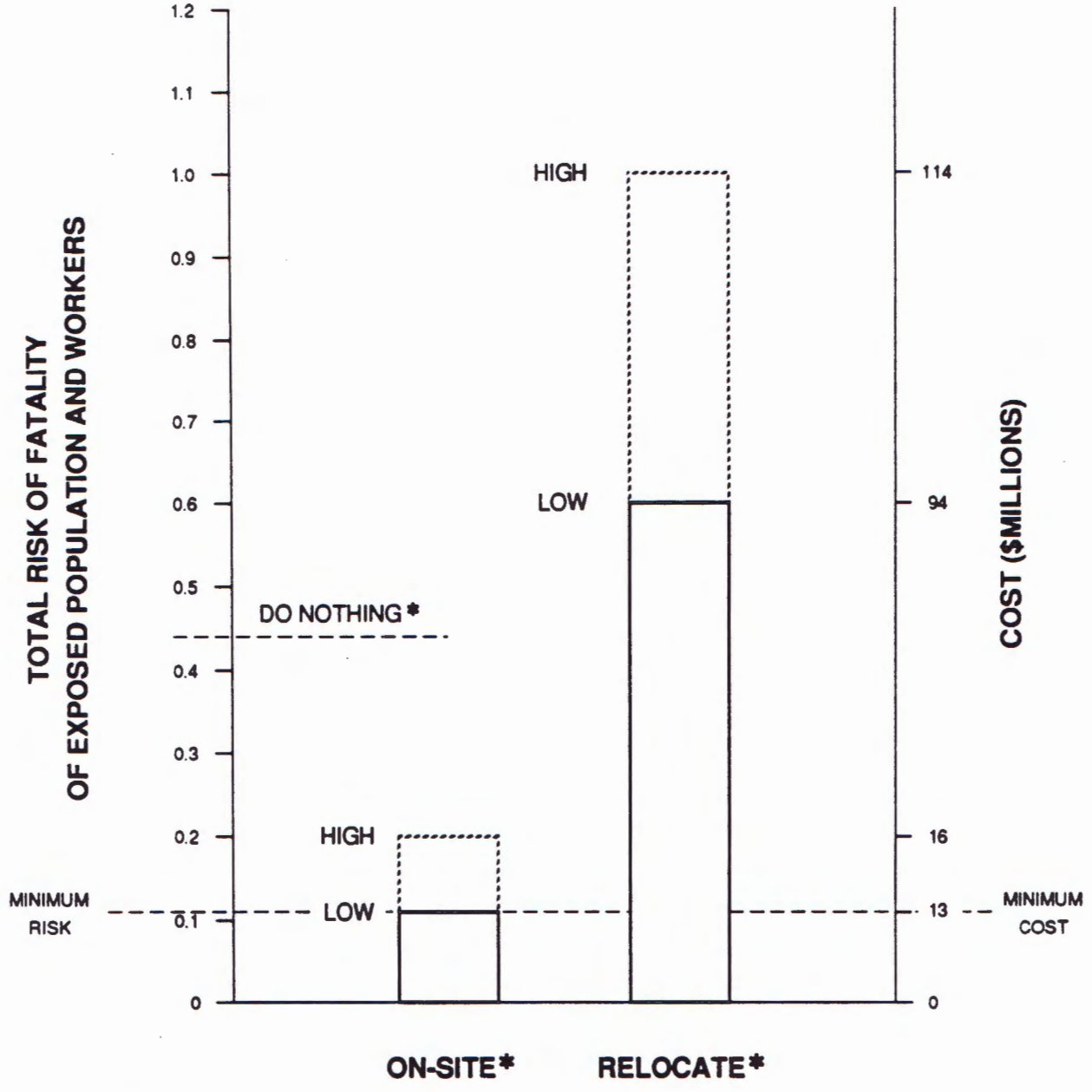
Conclusions

In 1992, the NRC reviewed and approved Atlas' plan for on-site reclamation of the Moab tailings. Subsequently, in 1994 NRC reversed their FONSI which lead to a review of the reclamation alternatives, the associated risks and the associated costs.

This paper summarizes the results of studies performed on behalf of Atlas. These studies considered many factors including: legal, policy, risk and cost. As discussed above, the overall risk, to the public and remediation workers combined, is about five (5) times greater for the relocation alternative than for *in situ* reclamation. A screening level uncertainty analysis on risk from radon-222 after *in situ* reclamation indicates such risk is small and likely to be less than about 4 mrem/y. Similarly, cost estimates for *in situ* reclamation versus relocation demonstrated that the cost for relocation would be about 6-9 times larger than the costs for *in situ* reclamation. Thus by either metric, risk or cost, *in situ* reclamation is the preferred alternative.

FIGURE 1

RISK / COST BENEFIT SUMMARY * FOR MOAB UTAH TAILINGS



NOTE:

1. SEE TEXT FOR DEFINITIONS *