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BENEFIT-COST ASPECTS OF LONG-TERM ISOLATION OF URANIUM MILL TAILINGS

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ABSTRACT

The Uranium Mill Tailings Radiation Control Act of 1978 provides for regulations for control of radon diffusion from uranium mill tailings to protect the public welfare. In developing these regulations, the Office of Nuclear Material Safety and Safeguards of the Nuclear Regulatory Commission has sought to establish the benefits and costs for alternative regulatory criteria. This report provides a perspective on some economic issues associated with long-term radiation effects from disposal of uranium mill tailings. The general problem of developing an economic rationale for regulating this activity is complicated by the very long-term and widespread effects which could result from radon gas diffusion associated with tailings piles. The economic issues are also complex because of the trade-offs between costs of disposal and intangible social values. When intergenerational implications were considered the traditional basis for discounting in a benefit-cost framework was found to shift. The appropriate rate of discount was found to depend on ethical assumptions and expectations about the relative welfare of future generations.

1. INTRODUCTION

Uranium mill tailings are by far the largest volume component of radioactive waste in the nuclear fuel cycle. These wastes consolidated into large "tailings piles" are a byproduct of the conventional uranium milling process. Perceived as a serious environmental and health threat, the Uranium Mill Tailings and Radiation Control Act (UMTRCA) of 1978 has been enacted in an attempt to address this problem. This paper attempts to provide a perspective on some of the economic issues involved in developing standards to achieve the objectives of UMTRCA of 1978.

The general problem of applying economic principles for regulating this activity is complicated by the very long-term and widespread effects which could result from tailings disposal. The economic issues are also complex because of the trade-offs between costs of disposal and intangible social values. The focus of this paper is on these trade-offs and on some issues of intergenerational choice they encompass. It is not intended as a comprehensive examination of the relevant economic theory but rather to provide a perspective on a specific problem. Section 2 provides a brief description of benefit-cost analysis and how it is relevant to providing a criteria for regulating disposal of uranium mill tailings. Section 3 describes the problem of radon control which is the main long-term health risk. Section 4 discusses some important economic issues associated with radon control and Section 5 provides a summary and conclusions.

2. BENEFIT-COST AND THE RADIATION CONTROL ACT OF 1978

Benefit-cost analysis is a well established and widely used mode of systematically identifying and measuring the economic benefits and costs of a program. Traditionally its most noted use and development has been associated with federal investment programs including water resource development, e.g., dams for flood control and irrigation. More recently, the use of benefit-cost analysis has been recognized as a useful aid for developing environmental policy. One area of current interest in this regard is development of regulations to implement the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978.[1,2]

As a basis for regulation, benefit-cost is explicitly concerned with conventional marginal analysis. In the context of regulating disposal of uranium mill tailings, marginal benefits and costs can be estimated for alternative regulations to determine the optimal regulation, i.e., where the net social benefits of the regulation would be at a maximum. A brief examination of the economic theory of pollution will help explain the issues associated with the regulation of uranium mill tailings as an environmental pollutant and the criteria for developing the appropriate regulation.

In the production and consumption of any activity, society will attempt to maximize its economic welfare by maximizing net benefits -- the difference between total social benefits and total social cost. In Fig. 1, the ordinate measures costs and benefits and the abscissa shows the level of pollution control. Total social costs are assumed to rise with higher levels of control. Total social benefits represent the value of damages prevented. From an economic perspective, an optimal policy is one that maximizes the net benefits of control. Net benefits are maximized when marginal social costs and benefits are equal (control level E in Fig. 1).

Unfortunately, the control of uranium mill tailings is fraught with many difficult measurement and valuation problems. Furthermore, there is considerable controversy over the economic efficiency concept of discounting in which long-term effects on the environment are uncertain. The use of a positive discount rate could lead to a total neglect of long run environmental and health consequences, even if there are substantial costs involved. Application of benefit-cost analysis could therefore ultimately lead to acceptance of significant health damages. Alternative approaches have been suggested. For instance, Krutilla and Fischer (1975)[3] argue that irreplaceable environmental assets should be appropriately valued to account for long run damage costs under economic development. And, Holling (1978)[4] advocated strategies that create information feedback on environmental impacts and to maintain flexibility over time.

Putting these problems aside for the moment, the justification for government intervention is to correct the market failure which results in foregoing net social benefits available from pollution control. When net social benefits from control are significant enough to warrant intervention, several approaches are available. One approach

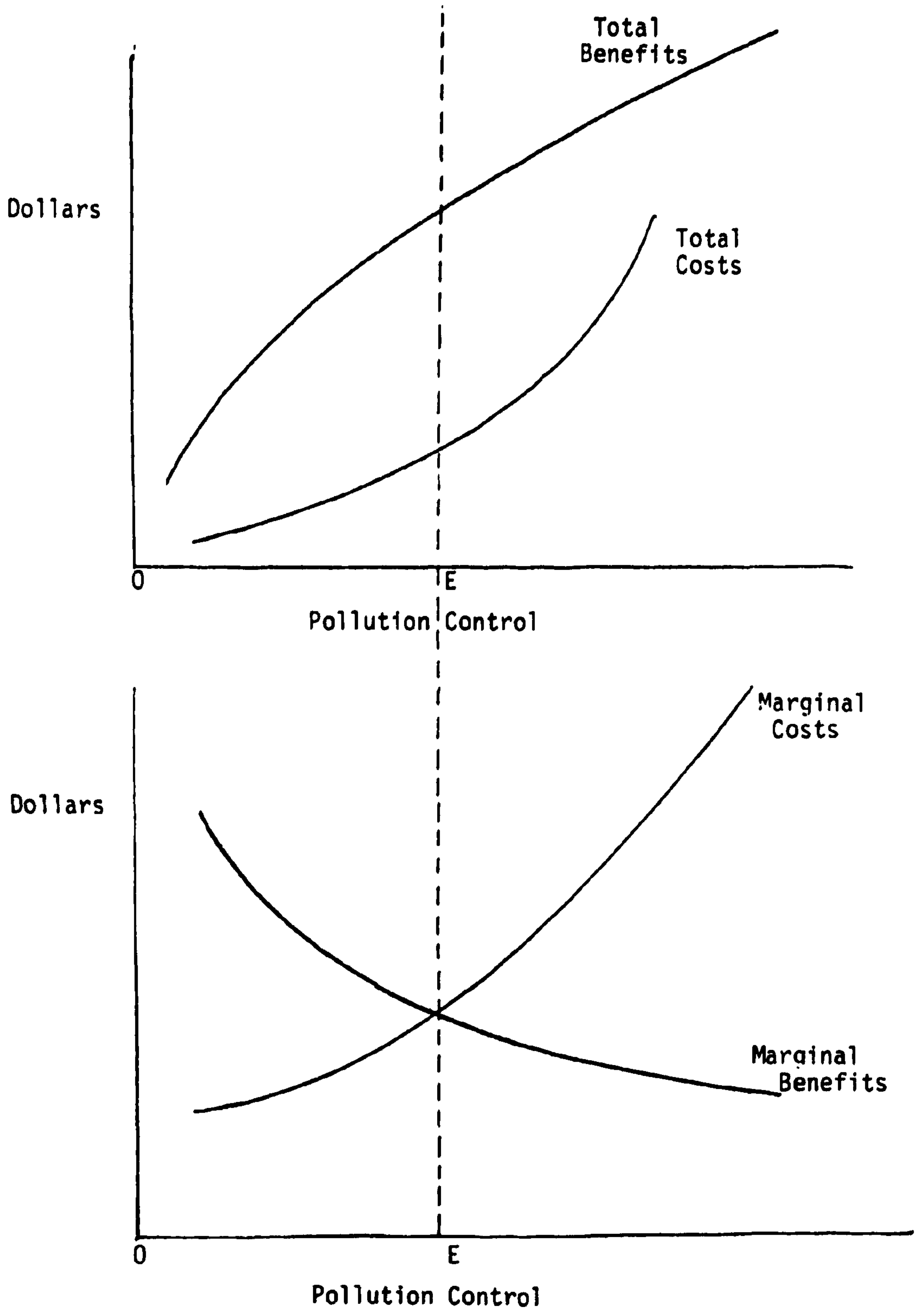

Fig. 1. Optimal uranium mill tailings control

is to regulate the disposal of the uranium mill tailings. This approach seeks to achieve control level E as portrayed in Fig. 1. In the case of pollution from uranium mill tailings, the UMTRCA of 1978 provides the legislative basis to regulate pollution associated with the uranium milling industry.

The following section describes a crucial long-term environmental problem associated with uranium mill tailings--radon escape and exposure. It is not the only environmental/health effect resulting from uranium milling; however, it is perceived to be the most important problem and the predominant long-term impact from uranium milling. Hence, it is the focus of this study.

3. RADON ESCAPE AND CONTROL

One of the major objectives of the UMTRCA is to protect the public health and safety from radon diffusion. Radon (Rn 222), considered the greatest single contributor to non-occupational health risks from uranium mill tailings, is a chemically unreactive gas associated with the decay of uranium-238.[5] Although radon has a half-life of less than four days and does not pose a direct health risk, it is transformed into radioactive "daughters" which emit alpha particles in a natural sequence of radioactive decay. It is this radioactive alpha emission that is considered a potential health risk. Radon gas is normally present at low levels in the atmosphere and is inhaled with each breath but is usually exhaled without irradiating respiratory tissue. However, radon daughters are heavy metals and become attached to available surfaces including small airborne particles which can easily be deposited in the respiratory tract when breathed. Thus airborne radioactive daughters of radon gas are the major health risk from uranium mill tailings.

The radioactive decay process resulting in radon gas and its radioactive daughters is naturally occurring and proceeds in unmined uranium ore. With mining and processing the radon gas can more readily reach the atmosphere before it decays to a heavy metal. In establishing a perspective it should be noted that uranium milling represents only a small incremental increase to naturally occurring background radiation. An estimate of the contribution from conventional tailings disposal practices as a fraction of radon release from natural soil in the U.S. is .0000046.[6]

Estimates of the health effects resulting from uranium milling activity have been developed in the Final Generic Environmental Impact Statement On Uranium Milling (GEIS).[7] These estimates provided in Table 1 indicate the cumulative number of premature deaths for various levels of radon flux at tailings disposal sites stemming from conventional uranium milling activity from 1979 through 2000.[8] The dose/effect relationship used in developing these estimates has been extrapolated from the estimated relationship observed at much higher radon exposure levels. The increased exposure of populations from milling activity has been modeled as a function of radon flux from tailings piles, prevailing meteorology patterns, and the location of existing human populations. The methodology used in estimating the effects stemming from radon is described in the GEIS.

In determining radon exposure levels from uranium mill tailings the increased level of radon flux can be considered equivalent to a constant level of increased flux for 100,000 years. The total cost of controlling radon flux over this period is very problematic because of the need for erosion control over a time period in which geologic processes must be considered. However, assuming the disposal design maintains its integrity, radon attenuation is a function of the depth of earth cover over the disposal site, and other factors equal, the depth of earth cover determines the cost of radon control to the industry. Table 2 presents estimates of the total industry cost and cost per death averted in

Table 1. Cumulative health effects for various radon flux limits

Flux Limit (pCi/m^2-sec)	Cumulative Health Effects 100 Years	1,000 Years	100,000 Years
100	214	2,140	214,[illegible]0
10	21	210	21,000
3	6	60	6,000
2	4	40	4,000
1	2	20	2,000
0.1	0	0	0

Source: Final Generic Environmental Impact Statement On Uranium Milling, NUREG-0706, Vol. 1, Table 12.5.

Table 2. Costs of control for various radon flux limits (1980$)

Flux Limit (pCi/m^2-sec)	Total Industry Costs ($M)	Cost Per Death Averted ($M) 100 Years	1,000 Years	100,000 Years
100	45.5	.316	0.0316	0.000316
10	215	3.51	0.351	0.00351
3	306	11.7	1.17	0.0117
2	336	17.6	1.76	0.0176
1	388	35.1	3.51	0.0351
0.1	562	351	35.1	0.351

Source: Final Generic Environmental Impact Statement on Uranimum Milling, NUREG-0706, Vol. 1, Table 12.5.

achieving various radon flux levels. This table provides the cost basis for determining the optimal level of radon abatement which will be returned to in Section 5. The next section discusses some crucial issues in evaluating changes in risk associated with radon control.

4. SOME ISSUES IN EVALUATING LONG-TERM RISKS

A significant challenge in using the benefit-cost tool is in estimating gains and losses associated with intangible values. Intangibles often relate to environmental, aesthetic, or risk factors that do not have explicit values such as goods and services with market prices. To the extent possible the benefit-cost methodology attempts to account for all the important consequences of a decision, measuring them with a common unit--the dollar. An important question then is whether benefit-cost analysis can be comprehensively and objectively applied to developing regulations for disposal of uranium mill tailings.

The most important policy issues associated with controlling radon lie with estimating the benefits for alternative regulatory requirements. Estimating the cost is equally important in determining an optimal level of abatement, however, costs associated with implementing standard abatement technologies are fairly well known. These costs are primarly composed of excavation, earth construction, transport, and materials. They can vary widely since they are site specific, but significant research has led to generic estimates for disposal at a prototypical mill site.[9,10] For purposes of assessing the optimal abatement level, the costs provided by the GEIS and presented in Table 2 will be used. If these costs are significantly biased this would become apparent as actual experience was gained in tailings disposal. If this were the case, requirements to achieve an optimal level of radon control could be adjusted.

One issue which pervades any attempt to estimate the benefits of regulating uranium mill tailings is uncertainty. Uncertainty could be considered the paramount issue in the long-run--pervading the relationship between health risk and radon exposure, the geologic and climatic factors that will determine disposal stability, and the economic and demographic trends that will influence social valuations in the future. This has obvious implications for benefit-cost analysis. Benefit-cost theory suggests that an uncertain prospect may be reduced to an equivalent certainty. For example, given an expected but uncertain benefit, an individual or society would presumably be willing to pay somewhat more to have that benefit with certainty. In other words, there would be a willingness to accept a reduction in the expected net benefit to achieve certainty. Thus, at an abstract level, uncertain values can be reduced to certain equivalents, but at a practical level estimation seems untenable.

Conservative assumptions about uncerta.n parameters is a common way to reduce uncertainty. For instance, at some additional cost, more gradual slopes for disposal designs reduces uncertainty about long-run erosion problems. The problem with this approach is that it is not based on empirical information about the t ade-off, only the general relationship between the variables is known. When uncertainty is strictly interpreted as ignorance about the probability distribution, there is no method for counting it in the benefit-cost calculation.[11] Therefore, uncertainty cannot be reduced to an optimal trade-off and should be considered separately.

Recognizing the above qualifications with respect to uncertainty, assessing the benefits of reducing radon levels may be viewed as involving two key issues. First, the social benefit of reducing risk to life at a single point in time; and second, integrating the value of reduced risk over time. These issues will be addressed by examining the relevant theory and empirical evidence. The health effects as estimated in the GEIS and presented in Table 1 are assumed as a basis for estimating the value of reducing risk.[12] As mentioned previously long-term health effects stem from radon gas releases from tailings piles and have been estimated from assumptions about population growth and weather patterns. Also long-term health effects have been estimated with the implicit assumption that medical advances do not result in a widespread cure or prevention for this type of life-shortening respiratory cancer. It is recognized that changes in these assumptions could imply considerable changes in estimates of aggregate health effects over the long run. However trends in population, weather patterns, and medical advances over such long periods of time are problematic and could be considered as an issue apart from benefit-cost (see above about uncertainty).

Society individually and collectively places implicit values on human life through health, safety, and environmental quality decisions.[13] In past studies, which have attempted to make this valuation explicit, several ways of estimating the value of a human life have been used.[14,15,16] The most common method is based on the loss of future income.[17] In this method the value of life is calculated as the discounted present value of future earnings of the person who dies from the risk. This type of calculation is rooted in the criteria of maximizing GNP. The problem with this approach is that the maximizing of GNP as the sole basis for calculation is at odds with social preferences. For instance, this criteria would on average discriminate against the elderly and other groups who have a low expectation of future earnings. Such a criteria could also be questioned since it is not pursued through immigration policy where accepting immigrants as long as the value of their marginal product was positive could significantly increase GNP.

Another method sometimes used, estimates the value of risk based on insurance. Accordingly, the amount of insurance purchased, divided by the probability of death that is insured against, gives the value of an individual's life. However this calculation does not value the life of the policy holder since life insurance is based on supporting the economic well being of others and not the life of the policyholder.[17]

A third method is the calculation of an implicit value of life based on public expenditures or regulations that require private expenditures to reduce risk. Such calculations are faulted as circular reasoning: the empirical calculation is derived from an earlier political process rather than independent economic criteria. If the political process is asking the question, it should not be used to provide the answer.[17]

The correct concept for valuing risk is termed the "compensating variation." *The compensating variation is defined as the money transfer* necessary following an economic change to maintain an individual's welfare at the prechange level.[18] For example, presumably there is some minimum amount of money a person would be willing to accept for a slightly increased risk of death. Alternatively, if risk is slightly reduced there would be some maximum sum which could be exacted which would maintain his welfare at the prechange level. In either case, in theory, the money transfer could be made to exactly compensate for the loss (gain) in welfare from the increase (decrease) in risk. This concept for valuing risk to human life is the familiar basis of measuring gains and losses through individual preferences. The correct value in calculating a public risk such as exposure to radon is the summation across all individuals of the net money value that would leave their welfare unaffected by the change in risk. This valuation of risk is consistent with the principles of benefit-cost analysis.[18]

Using this concept, a study by Thaler and Rosen[19] on the demand price of a person's own safety provides a starting point for estimating the value of changes in risk from uranium mill tailings regulation. This study addressed the question of the implicit value a person places on his own life by examining wage differentials of workers in job categories with varying levels of fatality risk. Economic theory indicates that in a competitive labor market with full information, various levels of occupational risk of death will be compensated through wage differentials. By statistically isolating the wage differential attributed to differences in risk, an implicit market price of risk was estimated. This study provided estimates which ranged from $136,000 to $260,000 per life in 1967 dollars. If the midpoint of this range is inflated by the CPI, the value of risk normalized per life in 1980 would be $489,000.

This estimate may be biased low as an estimate of the market value of risk. The wage differentials were derived from a selection of high risk occupations where less risk adverse individuals would presumably have a disproportionately high representation. Most people do not work at the higher risk jobs examined in the study and might require a higher premium for accepting risk than those studied. Also, these risks were valued in a private market where assumption of increased risk was voluntary and compensated. It follows that there may be important objections for using this figure in developing public policy where altering risk is in the nature of a public good, i.e., it is not voluntarily accepted or rejected and it is not directly compensated. Nevertheless this estimate will be considered as a first approximation and provides a minimum value on human life in evaluating public risk from radon exposure. A further qualification is that even if the Thaler and Rosen evaluation of risk is correct, it is established exclusively from the preferences of the generation studied. Future generations may develop significantly different preferences toward risk. Therefore using the Thaler and Rosen estimate as a constant value across all generations involves a crucially moot assumption.

Given an estimate of the value of incremental changes in the level of risk, there remains the crucial problem of how to aggregate these values over the period when changes in the level of radon occurred. Since radon releases from tailings will continue on the order of 100,000 years, risks are an issue for a very long period of time. However, as suggested by Table 1, there is an important question of the time horizon that should be considered in evaluating the health effects from tailings disposal. Under assumptions of constant population, exposure patterns and medical technology (i.e., no prevention or cure for radon induced cancer), widespread cumulative effects will tend to increase in direct proportion with the length of period evaluated. The important issue being considered is how the present generation's welfare should be linked to future generations. As can be seen in Table 1, the answer to this question has extremely important implications for estimating the benefits associated with controlling radon because very small health effects accumulate over an extremely long period. Table 2 demonstrates the impact of the time frame considered on calculating the optimal level of radon control. If the value of saving a life is assumed to be the Thaler and Rosen estimate, then the optimal amount of control is determined by selecting that level at which the marginal cost to industry is $489,000 per life saved. However, it should be clear from Table 2 that there is a different optimal level of control for each time frame considered. Three time frames, 100, 1,000, 100,000 years are considered and as the time frame considered increases, the incremental cost per death averted declines proportionally. This results in an extremely wide range of marginal costs per life saved at each level of radon control. Thus, the socially optimal level of control depends on the time frame chosen as appropriate for the evaluation. What should this time frame be?

The public sector evaluation of benefits and costs when they are not matched over time is commonly performed by discounting to a present value at the time when the action must be initiated. The rate of discount that is used is designed to reflect the trade-off that society is willing to make between the present and future. Often the rate of discount used to evaluate public investments is based on a market rate of return or rate of interest. This is justified because this is the rate of trade-off available in the private sector for another dollar of investment or consumption. If an investment cannot be expected to make some minimum rate of return then there are presumably opportunities in the economy that should be undertaken before this particular investment. In other words, there is an opportunity cost of public investment and this should be reflected through discounting.[20] Besides considering the opportunity cost of private investment funds, the discount rate often systematically incorporates the individual rate of time preference as indicated by rates available for individual investment and borrowing.

Positive rates indicate that at the margin consumption in the present is preferred to consumption in the future. It is therefore considered consistent with market preferences to discount all future benefits and costs.[21]

It should be noted that interest rates and rates of return are based on the principle of compensating investment (reduced consumption in the present) with increased opportunity for future consumption. They are a measure of market preferences and the opportunity cost of capital per unit of time and can be applied to revalue or discount dollar values which occur at different points in time to values commensurable at one point in time. Therefore over the life of a project if discounted benefits are greater than discounted costs (and benefits can be costlessly transferred) all costs can be compensated out of proceeds from benefits. This is a crucial point since it establishes that a project with a positive net present value can leave everyone at least as well off (by redistributing benefits to provide compensation) as they were without the action. In other words proceeds can compensate all future costs when the discounted benefits are greater than discounted costs and the discount rate is the interest rate at which project funds can be borrowed and invested.

The traditional approach of discounting as applied to effects from radon implies future effects from radon will be inconsequential in terms of their discounted present value. For instance at a 5% rate of discount,[22] a dollar of benefit in 95 years is worth less than one cent in terms of its discounted present value. So effects from radon that are far in the future would call for only minor consideration because very, very, small savings in terms of present resources could theoretically compensate future costs if these present resources were invested at a 5% rate of interest.

From this perspective, the cumulative present value of reducing radon effects after 500 years is trivial, yet this period of time includes more than 99% of the health effects for the 100,000 year time horizon over which risk from radon remains undiminished. The resulting dilemma is that discounting at approximately current rates of interest suggests most of the potential future effects from radon can be ignored for purposes of regulation.

In his classic work on benefit-cost analysis, Mishan suggests that "Whenever inter-generation comparisons are involved . . . it is well to recognize that there is no satisfactory way of determining social worth at different points of time. In such cases, a zero rate of time preference, though arbitrary, is probably more acceptable than the use today of existing individuals' rate of time preference or a rate of interest that would arise in a market solely for consumption loans."[23] Another view suggests that a positive discount rate is appropriate even though the government has interests in representing future generations. This argument is that a future dollar will produce less satisfaction assuming future generations will be richer through continuing economic growth.[24] Therefore an assumption is made about the relative wealth of present and future generations.[25] It seems clear that discounting extremely long-run effects such as those resulting from tailings disposal is essentially different than for discounting for more conventional short run projects. The difference is that compensating future generations in any traditional sense is not possible over such long time horizons. No financial institution could be expected to link present values to effects occurring 10,000 or 100,000 years from now. Under these circumstances one of the rationales for discounting, potential compensation to the future through current investment, does not exist. In other words, an important ethical basis that is implicit in discounting at the market rate of interest breaks down in the very long run.

Although this problem is not typically confronted in benefit-cost studies, some recent work has assessed traditional benefit-cost criteria in the context of ethic systems.[26,27,28,29] The focus of these studies has been on results from a model of intergenerational choice under commonly held ethical values. An examination of these arguments and results is relevant to evaluating disposal of uranium mill tailings.

Two of the value systems that have been examined and are often considered as a basis for economic policy can be characterized as utilitarian and libertarian. The goal of the utilitarian ethic is to maximize the sum of utility of society as a whole. For a society of two individuals, A and B, the social objective is to maximize utility as a function of income: Maximize $U_A(Y_A) + U_B(Y_B)$. In a study by William D. Schulze et al.,[29] a formal model of this ethical proposition has been formulated to examine the decision rule for pursuing nuclear power where the present generation would receive the benefits and a future generation would receive increased risks. Both benefits and risks were assumed to be a function of nuclear waste creation. The results of the analysis based on a utilitarian ethic depend on whether it is possible to compensate the future generation for the increased risk from waste disposal. Table 3 presents the criteria for discounting from this study and the implications for regulating radon under the utilitarian ethic. The criteria depends on the possibility of compensation. If compensation is possible then the benefits and costs should be discounted at the rate of return (interest rate) for the period. If compensation is not possible, then the benefits and costs should not be discounted which is equivalent to discounting at a rate of zero.

The rationale is that when compensation is possible the costs to the future generation can be compensated through an investment out of net benefits that accrues at the investment's rate of return. The discount rate is equivalent to this rate of return and it follows that if discounted benefits are greater than discounted costs, compensation is possible and the action should be taken. On the other hand when compensation is not possible, the costs to the future generation must be counted directly as costs to the present generation without discounting; discounted costs are not relevant. The costs to the future generation

Table 3. Ethical Criteria and Implications for Discounting

	Compensation to Future	No Compensation to Future
Utilitarian Ethic	Use a discount rate equal to the rate of return on investment. Set radon level where <u>discounted</u> marginal <u>benefits</u> equal discounted marginal costs of abatement.	Use a discount rate equal to zero for costs and benefits to future generations. Set radon level where marginal benefits equal marginal costs of abatement.
Libertarian Ethic	Same as above.	Discounting is not relevant. Set radon level at zero.

have to be made up on a one for one basis with benefits to the present generation. Present generation benefits can not be matched against the easier criteria of discounted costs since interest rates cannot effectively link the two generations.

An alternative decision criteria may be developed from the libertarian ethic which emphasizes individual rights as having priority over the good of the whole. An individual action is ethical if it harms no other individual. This ethic is partially reflected in the familiar economic criteria where an action is acceptable if it makes at least one person better off and no one worse off. The criteria for the libertarian ethic requires that any change from an initial social order should harm no one. For two individuals comprising a society, this can be written symbolically $U_A(Y_A) \geq U_A(Y^oA)$ and $U_B(Y_B) \geq U_B(Y^o{}_B)$ where Y^o is the initial income. This reflects a decision rule to evaluate any proposed action. A model using this rule as a constraint was used to answer the same question about pursuing nuclear power as described above.[29] The objective under the libertarian ethic is to maximize the utility of the present generation subject to the constraint that the future generation (any future generation) can be no worse off than its initial position. Table 3 presents the appropriate criteria for discounting and the implications for regulating radon under the libertarian ethic. Once again the criteria depends on the possibility of compensating the future generation. When compensation is not possible then any risk imposed on the future generation would violate the libertarian ethic because the future generation would be made worse off than in its initial position. This result differs from the utilitarian criteria in that actions resulting in uncompensated risks should not be pursued under any circumstances. On the other hand, when compensation is possible then a discount rate equal to the rate of return should be used to evaluate the benefits and costs. As under the utilitarian ethic, when compensation is possible then costs discounted at the rate of return provide an adequate measure of the compensation necessary to offset costs and leave the future generation no worse off than its initial position.

As mentioned previously, compensation to the second generation when it stretches for 100,000 years is not possible--at least in any traditional sense. Institutions established to provide compensation could not be expected to last even a small fraction of this time. Of these ethical systems only a zero rate of discount implying a utilitarian ethic is feasible if wastes put future generations at risk.

Other ethical systems could provide a rationale for a non zero rate of discount when compensation is not possible. These alternative systems are more controversial and the discount rates they imply are based on expectations about intergenerational income distribution.[21] For instance, an ethical criteria with an objective to maximize the minimum income of present and future generations would call for an infinite intergenerational discount rate (whatever rate maximizes benefit to the present) when future generations are expected to be richer than present generations. This would imply that costs should be imposed on the future without compensation when this would benefit the present. The belief that the future generations would be poorer than the present would mean that no uncomper[illegible]ted costs should be imposed on the future. Thus, a decision to imp[illegible]mpensated costs under this ethic is based on a belief about income to future generations relative to present generations.

One conclusion of this analysis is that ethical beliefs are important in determining the appropriate discount rate. A further conclusion is that the market rate of interest does not have the traditional justifications for use as a discount rate over long periods of time because it seems very unlikely that traditional institutional linkages would hold. Finally, not being able to provide future generations with compensation precludes the option of burdening them with costs under certain ethical systems.

5. CONCLUSIONS

Although uranium tailings regulation has many aspects of problems typically encountered in benefit-cost analysis, it involves one important distinction. The extremely long time horizon which must be considered makes intergenerational choice a dominant economic issue. As suggested in the previous section, traditional benefit-cost does not adequately account for this issue because it has been designed and applied to problems that link present and future values with an interest rate as the basis for discounting. When periods are very long this linkage does not seem justified, and an important implicit ethical consideration, i.e., the ability to compensate breaks down.

The ethical criteria portrayed in Table 3 suggest that since compensation is not feasible, that either the radon level should be regulated at 0 or that the regulated level should be set at the level where the marginal costs of reducing the radon level are equated to the marginal undiscounted benefits aggregated across all generations. Using Table 2 as a basis for the relationships between incremental costs and health effects, the previously described estimate for the value of risk avoided ($489,000 per death) would more than justify the cost per health effect ($351,000) for 100,000 years at a radon flux limit of 0.1 pCi/m^2-sec (essentially zero). Thus under cost assumptions presented in the GEIS, the regulation would be equivalent for both utilitarian and libertarian ethics. This conclusion is reinforced since the costs of reducing radon flux were not discounted in the GEIS and unlike health effects to future generations, it is appropriate to discount the short-run costs of providing abatement from 1979-2000.

Other ethical criteria such as maximizing the minimum income of present and future generations could be used as the basis for economic evaluation. If it were assumed that future generations would be richer than present generations this ethic could justify a flux limit even higher than 100 pCi/m^2-sec.[30]

In conclusion, it can be stated that the long-run health effects from disposal present a unique problem for economic analysis. Traditional methods of calculation within the benefit-cost framework do not seem appropriate because compensation to generations far in the future is not possible. Recommendations for an optimal regulation vary with respect to the ethical value that is assumed.

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19. R. Thaler and S. Rosen, "The Value of Saving a Life: Evidence From the Labor Market," in Household Production and Consumption, D. E. Terleckys, ed. (Columbia University Press, New York, 1975), pp. 265-297.

20. There is a long standing controversy on the relationship between the discount rate and rates of return in the private sector. These arguments revolve around the appropriate adjustments for risk, distortions in the market, and the rate of interest for consumption. For a detailed discussion of these arguments see: Robert C. Lind, "A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options," in Discounting for Time-and Risk in Energy Policy, Robert C. Lind, ed. (Resources for the Future, Inc., 1982), pp. 95-114.

21. Kenneth J. Arrow, "The Rate of Discount for Long-Term Public Investment," in Energy and the Environment: A Risk-Benefit Approach, Holt Ashley, Richard L. Rudman, and Christopher Whipple, eds. (Pergamon Press, New York 1976), pp. 113-140.

22. The rate of 5% is used as an approximation of a real rate of interest, i.e., after inflation. With respect to discounting health effects from radon, almost any non zero rate of discount has the effect of making the present value of these effects trivial.

23. Mishan, p. 209.

24. Arrow, pp. 113-140.

25. A related argument is whether a risk of death will have approximately the same value in the future as it does today, i.e., whether utility functions will remain approximately the same as they are today. If the marginal value of risk changes over time then a valuation of changes in risk to the future based on today's preferences is inappropriate.

26. Ralph C. d'Arge, William D. Schulze, and David S. Brookshire, "Carbon Dioxide and Intergenerational Choice," The American Economic Review, May 1982, pp. 251-256.

27. William D. Schulze, "Ethics, Economics and the Value of Safety," in Societal Risk Assessment: How Safe Is Safe Enough?, Richard C. Schwing and Walter A. Albers, Jr., eds. (Plenum Press, New York, 1980), pp. 217-231.

28. William D. Schulze and Allen V. Kneese, "Risk in Benefit-Cost Analyais," Risk Analysis, Vol. 1, No. 1, 1981.

29. William D. Schulze, David S. Brookshire, and Todd Sandler, "The Social Rate of Discount for Nuclear Waste Storage: Economics or Ethics?," Natural Resources Journal, October 1981.

30. If 100 years is taken as encompassing the interests of the present generation, after discounting both costs and benefits (benefits attributed to reducing health effects are discounted over a longer period) the \$489,000 in benefits per health effect would be less than the \$316,000 cost per health effect averted at a flux limit of 100 pCi/M^2-sec (see Table 2).

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