ECONOMIC ANALYSIS OF ALTERNATIVE LLW DISPOSAL METHODS

C. Elliot Foutes
U.S. Environmental Protection Agency
Washington, D.C. 20460

ABSTRACT

The Environmental Protection Agency (EPA) has evaluated the costs and benefits of alternative disposal technologies as part of its program to develop generally applicable environmental standards for the land disposal of low-level radioactive waste (LLW). Costs, population health effects and Critical Population Group (CPG) exposures resulting from alternative waste treatment and disposal methods were developed and input into the analysis. Our impacts tables associate with each level of a given millirem standard an estimate of population health effects and disposal costs incremental to a base case (current practice).

The cost-effectiveness analysis took into account a number of waste streams, hydrogeologic and climatic region settings, and waste treatment and disposal methods. Total costs of each level of a standard included costs for packaging, processing, transportation, and burial of waste. Benefits are defined in terms of reductions in the general population health risk (expected fatal cancers and genetic effects) evaluated over 10,000 years. A cost-effectiveness ratio, defined as the incremental cost per avoided health effect (in moving from one level of a standard to another) was calculated for each alternative standard. This paper describes the alternatives considered and preliminary results of the cost-effectiveness analysis.

INTRODUCTION

Under its authority from the Atomic Energy Act of 1954 (AEA) and Reorganization Plan #3 of 1970, EPA is developing a generally applicable environmental standard for the disposal of Low-Level Radioactive Waste (LLW)(1). Commercial sources of LLW include nuclear power reactors, uranium hexafluoride conversion and fuel fabrication facilities, industries involved in the manufacture of radiochemicals, pharmaceuticals, smoke detectors, and luminous dials, and institutions generating LLW during medical and research activities. In addition, EPA is considering regulation of certain non-AEA wastes using a different regulatory authority. These non-AEA wastes (e.g., radium sources) are generally referred to as Naturally Occurring and Accelerator-Produced Radioactive Materials (NARM).

EPA's Office of Radiation Programs has devoted considerable effort over the past several years to fulfill this responsibility by modeling radionuclide movement through the environment and by conducting extensive analyses of the cost and health impacts associated with various disposal methods. The purpose of this paper is to discuss some of the elements of the cost-effectiveness analysis developed to support the LLW standard. These include an analysis of the costs and risks for alternative disposal option combinations; least cost methods to comply with alternative CPG dose levels; and the cost-effectiveness of alternative levels of a standard in terms of cost per avoided population health effect.

OVERVIEW OF LLW

Between 1985 and the year 2004, it is expected that approximately 4.5 million cubic meters of LLW and NARM will be generated by both the commercial sector and DOE sources(2). These estimates are based upon a review of previous estimates of volumes derived by both NRC and DOE but taking into account the significant number of nuclear plant cancellations and other changes that have occurred since EPA's original estimates were made in 1982(3,4).

EPA's LLW source term is essentially the same as NRC's with the exception of the previously mentioned NARM waste(5). The NARM waste would largely consist of two higher activity NARM streams: radium ion-exchange resins from drinking water purification and radium needles and sources (which includes radium-beryllium neutron sources)(6).

EPA is currently developing a Below Regulatory Concern (BRC) criterion that would allow for the the unregulated disposal of certain very low activity waste streams without regard to their radioactive content. For both commercial and DOE waste, it is likely that the implementation of those BRC criterion levels being given serious consideration by EPA in its BRC developement process would permit an estimated 30 to 35% of all LLW to be disposed of by less stringent (and less expensive) means than it would otherwise be required to meet(7). A more detailed discussion of the potential BRC waste streams and EPA's BRC criteria is presented by Holcomb in Session 10 of this Symposium(8).

Our projections for waste volumes over the 20 year generation period 1985 to 2004 are for a total commercial volume of LLW of approximately 2.9 million cubic meters or 66% of the total volume of all LLW (4.5 million cubic meters). Of this amount, between 30 to 35% might be expected to qualify as BRC waste, depending upon the level of the BRC criteria that EPA ultimately chooses. The ultimate percentage is also highly dependent upon the fashion in which NRC implements.

EPA has conducted no specific risk assessment on Department of Energy (DOE) waste. For purposes of this analysis deference has been made to DOE advisement (9,10) that the specific nuclides present, as well as their concentrations and physical characteristics, are assumed to be approximately the same as those found in commercial waste (without its NARM component). The projected DOE portion of all LLW in our analysis is approximately 34% or 1.5 million cubic meters. Since it is assumed for purposes of this analysis that DOE and commercial waste (without its NARM component) are identical, this is extended to the BRC component. We would presume that approximately 30 to 35% of DOE waste might qualify as BRC waste, again depending upon the level of a BRC criteria that EPA ultimately chooses. This figure is also heavily dependent upon the way in which DOE implements a BRC criterion.

The volume of NARM waste projected to be disposed of over the same time frame is extremely small--a total of 6,600 cubic meters making up 0.15% of the total volume of LLW.

Because of the differences between commercial and DOE waste in their disposal costs and risks and because of the limited space available here to discuss the results of our analysis, we will show results and impacts only for the commercial LLW sector. We will allude to DOE waste only insofar as we will want to mention the potential impact of EPA's standard on DOE.

DISPOSAL PRACTICES

The disposal practices that we have examined in our economic analysis are detailed in Table I. These ranged from a regulated sanitary landfill through what is termed 'current disposal practice' (disposal consistent with NRC's 10CFR61 performance objectives) to more stringent options such as concrete canister and earth mounded concrete bunker (EMCB) methods. These options are described in more detail in a report done for EPA(11,12). In addition, we examined several processing and packaging options for each disposal option (such as incineration and solidification), what are referred as pretreatment options. These have also been defined in Table I. By choosing a wide range of disposal practices for analysis, we were able to explore a broad spectrum of costs and risks. More detailed descriptions of disposal options 1 through 8 are available in EPA's draft Background Information Document (BID) on the LLW standard (3).

TABLE I

Disposal Options and Pretreatment

DISPOSAL

DISPOSAL OPTION	ACRONYM
Regulated Sanitary Landfill	SLF
Shallow Land Disposal	SLD
Improved Shallow Land Disposal	ISD
Current Disposal Practice (Combination of SLD and ISD)	10CFR61
Intermediate Depth Disposal	IDD
Hydrofracture	HF
Deep Well Injection	DWI
Deep Geological Disposal	DGD
Concrete Canister	CC
Earth Mounded Concrete Bunker	EMCB

PRETREATMENT

WASTE FORM OPTION	ACRONYM
Packaged as Generated	AG
Solidified	S
Incinerated, Then Solidified	I/S
Packaged in a High Integrity Container	HIC

DISPOSAL COSTS

EPA's cost analysis consisted of four disposal cost components: packaging, transportation, processing, and burial. The sum of these cost components equals total disposal cost. These components include all of the costs that vary among different disposal practices. Transportation costs were based on market prices, whereas other costs (burial, packaging, processing) were based on engineering estimates since many of these types of facilities do not yet exist(13,14). Because waste emplacement cost is only a fraction of the total disposal cost, variations in emplacement costs alone do not provide an accurate picture of the costs of disposing of LLW. Therefore, it seemed best to present the total cost of disposal by method on a national basis. These costs are presented in Fig. 1. Again, these are national totals and represent the cost of disposing of the total U.S. volume of commercial LLW and NARM waste generated over a 20 year period (1985-2004) by the indicated disposal method. Costs are discounted at a 10 percent real rate over this period and are expressed in 1985 dollars.

That portion of LLW assumed to qualify for BRC disposal under the most stringent implementation assumptions (approximately 25% of the total volume) has also been removed from the total of LLW to provide a more realistic estimate of what the actual disposal cost for the overall standard might be. The costs of its unregulated disposal is relatively insignificant.

For near surface options, the cost of disposal of commercial LLW and NARM waste could range from $1 billion (for a sanitary landfill with the waste in an as generated form) to $5.4 billion (for EMCB). Under current practice (10 CFR 61), the cost of disposal would be approximately $1.6 billion (Disposal of the total volume of both DOE and commercial waste using 10 CFR 61 would result in a total national cost of approximately $2.1 billion)(7)

It is important to note again that the costs shown are for the use of one type of technology nationwide to dispose of the total national volume of LLW and NARM, which is one of several possible ways in which EPA's regulation may be implemented. The way in which a LLW regulation is implemented has a large influence on the ultimate social cost of the regulation and the concomitant health effects. The different implementation assumptions that EPA has

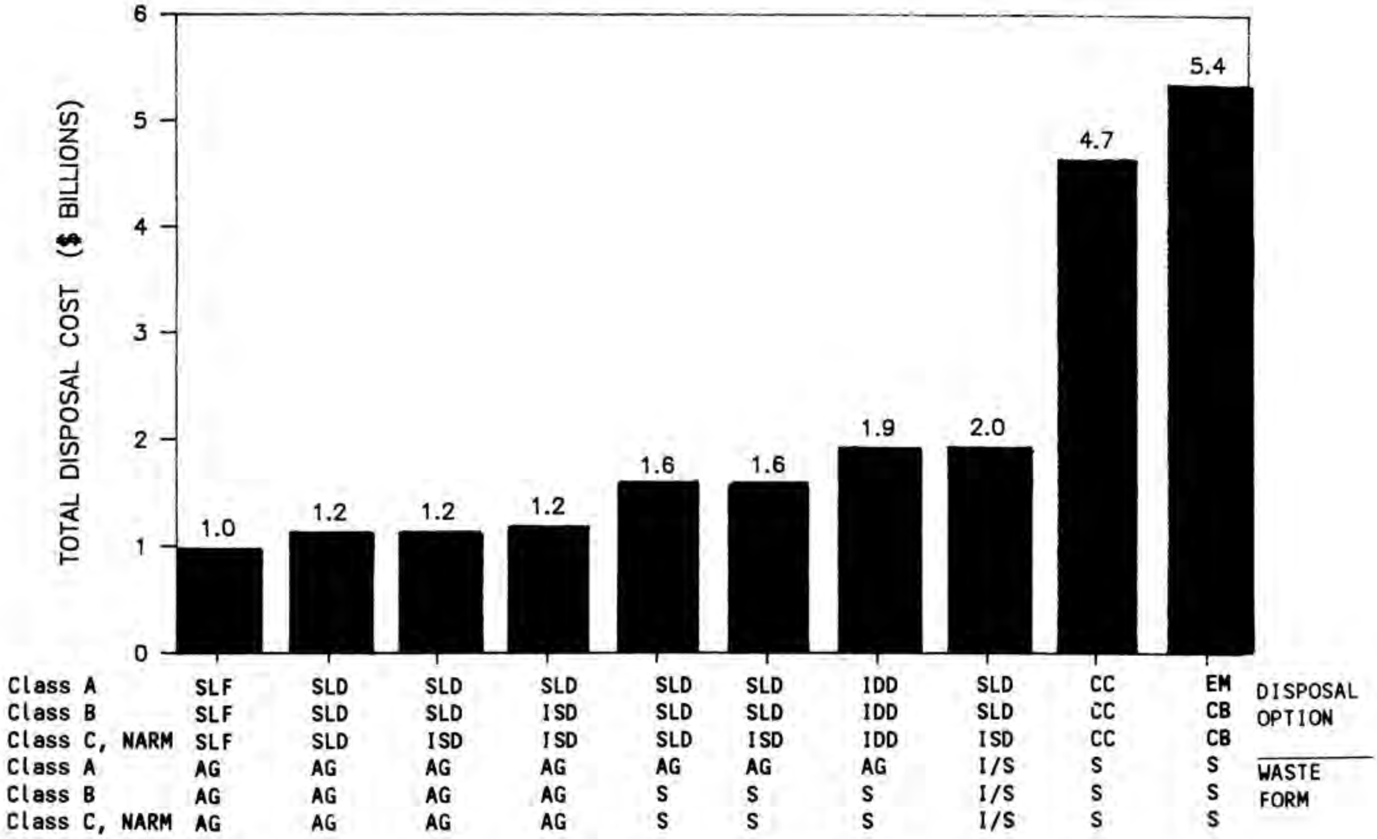

Fig. 1. Comparison of Costs By Method.

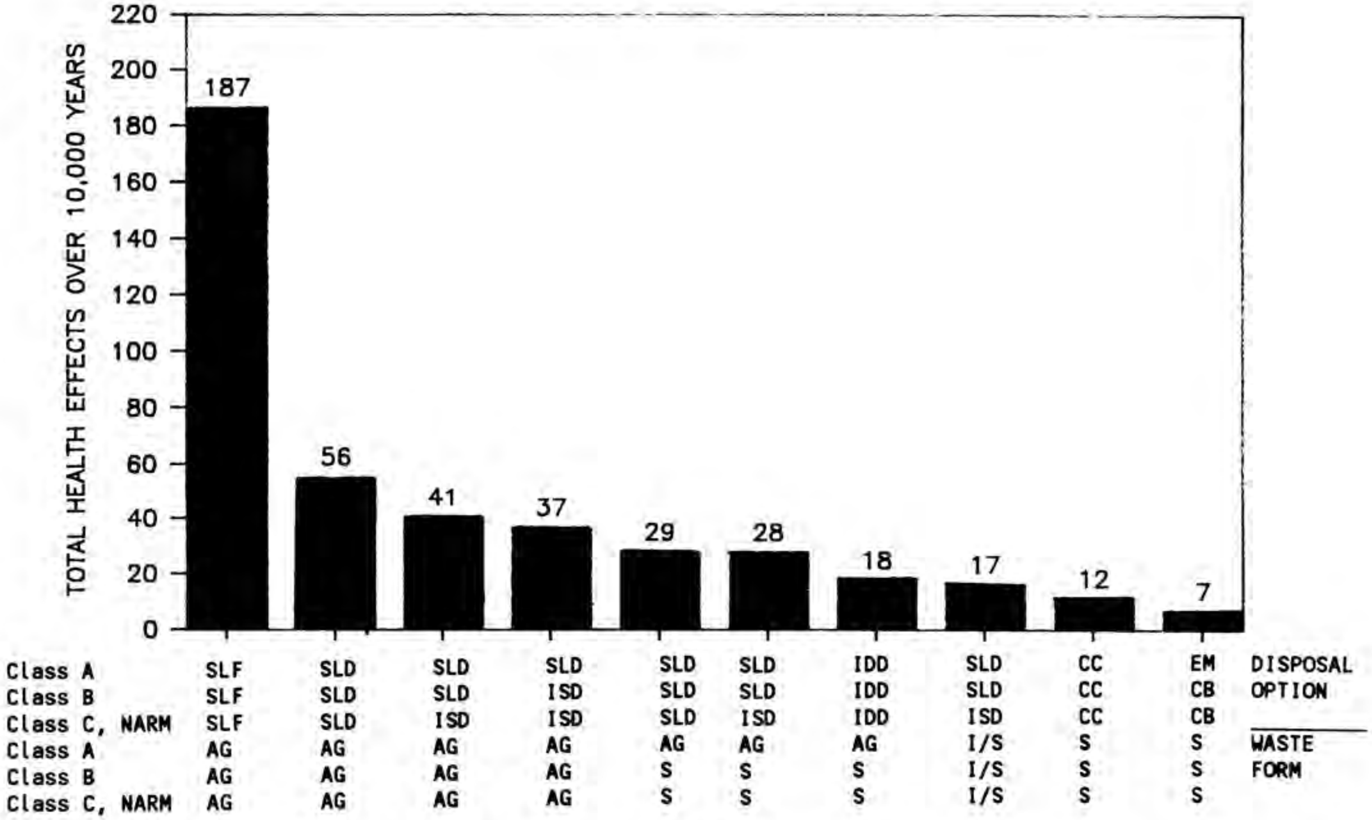

Fig. 2. Comparison of Population Health Effects.

examined in its impacts analysis are mentioned in a later section.

Costs for disposal also show a large variation when examined on a waste stream by waste stream basis for each of the disposal methods analyzed. Looking for comparative purposes at only one disposal method, conventional shallow land disposal (SLD), a five-fold difference is exhibited between waste streams. Total disposal cost on a per cubic meter basis as applied in this analysis range from $830 for light water reactor (LWR) compactible trash and institutional compactible trash through $2000 for LWR ion-exchange resins to nearly $3900 for institutional absorbing liquids. Most of the difference in costs between these wastes is due to packaging and transportation costs.

POPULATION RISK FOR THE VARIOUS DISPOSAL METHODS

Population risk, as used in EPA's risk assessment, includes statistical fatal cancers and genetic effects expected to occur over a 10,000 year period from a 20 year national volume of waste. These estimates are based on hydrogeologic modeling of radionuclide release and transport, using the PRESTO-EPA family of computer codes and EPA's risk assessment models (DARTAB, RADRISK)(15,16,17,18).

Figure 2 provides a comparison of population health effects by disposal option on a national basis. As shown, population risk for the near surface disposal options ranges from about 187 health effects for a sanitary landfill with the waste in an as generated form, to about seven health effects for the concrete canister method. For current disposal practice, (10 CFR 61) we would estimate about 28 health effects over the same 10,000 year period. Our modeling shows that most of the risk reduction benefits of more stringent disposal (i.e. going from conventional shallow disposal to 10 CFR 61) are gained during the first 1000 years(7).

As with costs, health effects per cubic meter of waste also show a large variation between waste streams. Using a weighted national average (i.e an average across all hydrogeologic regions) derived by dividing total national health effects by waste stream volumes, this variance can be demonstrated. SLD is again chosen as the disposal method used to make this comparison. Looking at it on a per cubic meter basis, radium sources, a NARM waste, would produce some 107 health effects per cubic meter of waste disposed of via SLD, lwr ion-exchange resins would produce 2.8E-04 health effects per cubic meter, institutional absorbing wastes, 1.4E-04, and lwr compactible trash would produce about 3.8E-07 health effects per cubic meter of waste.

The large variation in population risk, nine orders of magnitude between waste streams, together with the observed variance in costs between waste streams would suggest that, on a cost-effectiveness basis, the ideal would be to disposal of different waste streams in different fashions (given that the different disposal methods and pretreatment options also differ in population protection and cost). It should be noted that the waste classification scheme embodied in 10 CFR 61 appears to be a recognition of this fact. The results of EPA's analysis would suggest that this is a rational approach to the problem of disposing of the different waste streams that make up low-level and NARM waste as efficiently as possible.

CPG DOSE AND COMPLIANCE WITH ALTERNATIVE STANDARDS

CPG dose, as used in EPA's risk assessments, is the maximum annual whole body exposure, in millirems per year, to an individual within the Critical Population Group (CPG). The individual is assumed to live at the boundary of the waste disposal site and to receive the annual whole body dose over a 71 year lifetime. EPA's PRESTO-EPA-CPG model was used to predict the movement of radionuclides through environmental pathways and various risk models to translate uptake or exposure into a maximum annual dose(15,16,17). The CPG calculations were taken out to 1000 years only instead of the 10,000 for our population health effects analysis. Sensitivity analysis showed no significantly higher CPG dose after this time period(19). Since EPA expects the form of its generally applicable environmental LLW standard to consist of a CPG dose limit, CPG dose determines compliance with any anticipated standard.

Figure 3 shows CPG doses for 10 disposal options. These doses reflect the performance of that option in the hydrogeologic region producing the highest CPG dose. For the disposal options evaluated by EPA, estimated CPG doses range from 62 millirem per year for a sanitary landfill with the waste in an as generated form to about 1 millirem per year for concrete canisters. The estimated CPG dose from the use of 10 CFR 61 technology disposal was about 9 millirem per year.

Again, these are the results for the hydrogeologic region producing the highest CPG doses, and so do not reflect the large variance observed between hydrologic regions. For example, the use of 10 CFR 61, as just mentioned, produced a dose of 9 millirem in the humid permeable regions. However, in the humid impermeable regions, a dose of only 0.03 millirem is given to the CPG and in the arid permeable regions the dose to the CPG is only 0.0009 millirem.

This variance of orders of magnitude in CPG dose exists for nearly all disposal methods. Given this, it is plain that the disposal method that could be used to meet the millirem standard in each hydrogeologic region at least-cost could vary dramatically. Costs of disposal then, on a per cubic meter basis, might vary substantially between compacts in different hydrogeologic regions if the different compacts were to only use the disposal technology necessary to meet a millirem standard as opposed to using one method nationwide. The analysis shows a differential of nearly $300 million between this method of implementation (that is, by region) and the use of 10 CFR 61 technology nationwide, the base case assumption used in this analysis.

Population risk among the hydrogeologic regions for a given disposal option also varies but since population risk is not the form of the standard it is not a constraint here and so not discussed. Population risk variations are, however, discussed in some detail in a paper by Meyer(20).

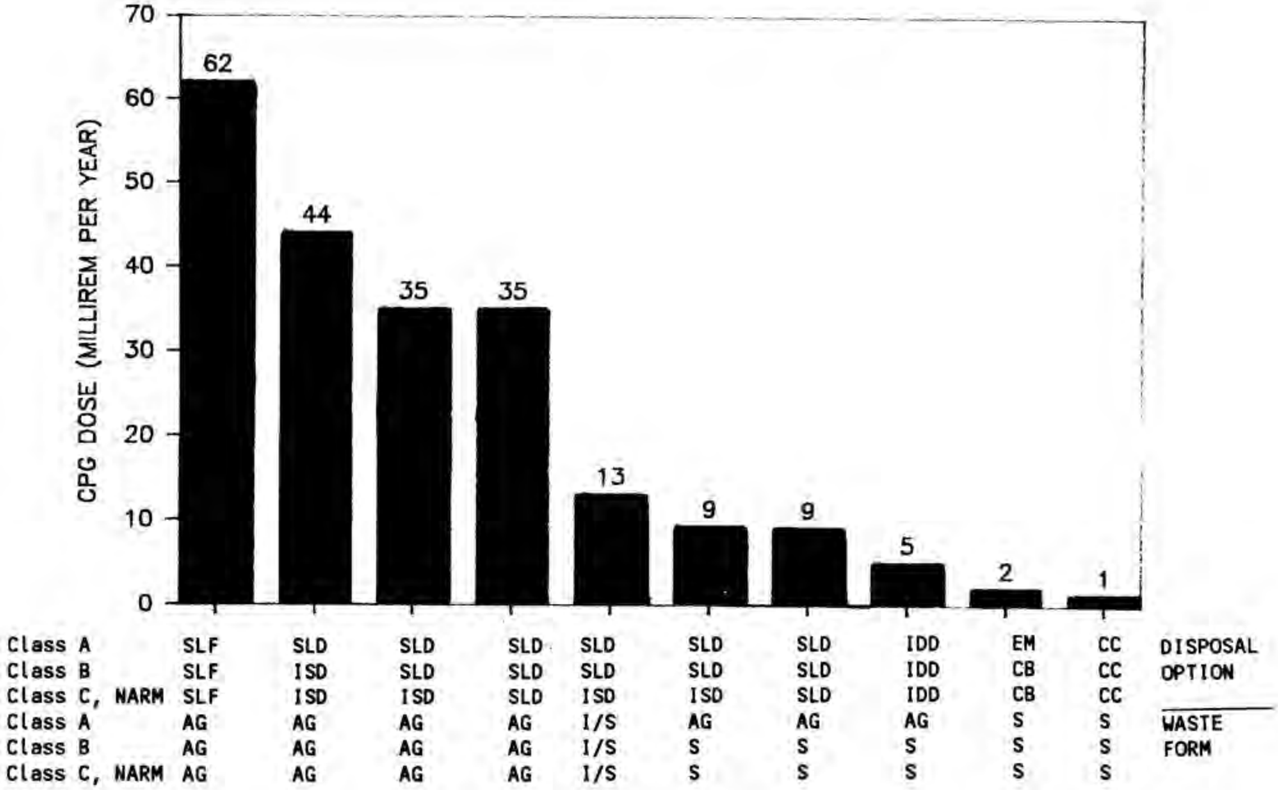

Fig. 3. Comparison of CPG Dose.

TABLE II

IMPACTS OF ALTERNATIVE LLW STANDARDS

LLW STANDARD (MAXIMUM CPG DOSE)	DISPOSAL OPTIONS	INCREMENTAL COST VS. CURRENT PRACTICE (*) ($ MILLIONS)	AVOIDED HEALTH EFFECTS VS. CURRENT PRACTICE (*)	MARGINAL COST-EFFECTIVENESS ($ MILLIONS PER AVOIDED HEALTH EFFECT)
100	SLF, AG	-590 (1,025)	-160 (188)	
				1.1
50	SLD, AG	-445 (1,170)	-28 (56)	
				16
25	10 CFR 61	0 (1,628)	0 (28)	
				34
5	IDD: Class A, AG; Class B,C & NARM, S	334 (1,980)	10 (18)	
				248
2	CC	3070 (4,740)	21 (7)	

Costs represent present values at a 10 percent real discount rate, expressed in 1985 dollars. Health effects include fatal cancers and genetic effects over 10,000 years, and are not discounted. Costs and health effects are for COMMERCIAL AND NARM WASTE ONLY.

(*) Current practice assumes commercial LLW is disposed of in compliance with 10 CFR 61.

ECONOMIC IMPACTS OF ALTERNATIVE LEVELS OF A STANDARD

In comparing alternative standards, we will use the assumption that compliance with any given alternative standard would be achieved using the least-cost disposal method meeting the standard on a national basis. That is, costs and health effects are premised on the use of a single disposal technology nationwide stringent enough to meet the CPG millirem standard in the highest millirem exposure hydrogeologic region. This methodology allows us to easily define the disposal option or mix of options that would meet each level of a standard, and hence the costs and population risks of those alternative levels.

Table II demonstrates the least-cost methods that our analysis shows would be used to meet the five alternative CPG standards considered here and the incremental cost and population risk associated with each (incremental to the base case, 10 CFR 61 disposal for all commercial waste)(7). At this point, since the costs and risks for the different levels are known, we can determine the marginal cost-effectiveness of alternative standards, that is, the cost-effectiveness at the margin associated with each level of a standard proceeding from one level of a standard to a more stringent one. The marginal cost-effectiveness, as mentioned previously, is a measure of the average cost per health effect avoided as one goes from one level of a standard to another.

It is important to note that in the discussion of the disposal option combination predicted to meet a given level of a standard, there is no implied approval or recommendation of any method. Although we have considered many different types of waste disposal in doing the economic analysis, our analysis does not imply an endorsement of any specific option. Rather, the economic analysis is used to predict the costs that might be incurred by society through the promulgation of various standards.

The economic analysis as shown also assumes that the disposal regulations of other agencies (e.g. NRC's 10 CFR 61 performance objective of 25 millirem) would be relaxed if a higher millirem standard were chosen by EPA. For example, the analysis shows a cost savings for standards above 25 millirem (i.e. at 50 and 100 millirem). The analysis has been conducted in this fashion because it reveals the regulatory action EPA would undertake based solely on the societal merits of that action and independent of what actions other regulatory authorities have undertaken. Marginal cost-effectiveness is then indicative of the economic rationality of the decision to go from one level of a standard to another based solely on societal cost-benefit criteria.

The regulatory actions of other agencies are accounted for, however, when the incremental costs of the standard at or above current regulatory criteria are presented. In this instance we show the cost for a 25 millirem standard being zero (for the commercial sector) to reflect the fact that 10 CFR 61 exists and currently establishes a 25 millirem limit for commercial waste. As the standard becomes more stringent, the costs shown for a 5 and a 2 millirem standard express the differential between the technologies used to meet those standards and 10 CFR 61, that 'extra' amount over and above current disposal standard costs.

Incremental costs and health effects over and above our assumed base case for each level of a standard and associated disposal method are shown in Table II . The incremental costs and health effects are the ones focused on here (as opposed to the absolute costs and health effects shown in the comparison tables in the first few sections of this paper) for several reasons. Only the incremental costs and benefits of any action reflect the true economic costs and benefits of EPA's action to society as opposed to the status quo case. That is, the question that we are asking (and answering) here is not what the total costs and health effects of a level of a standard might be. These do not take into account the costs that would have been incurred in the absence of any action on EPA's part and are due to other governmental regulations or private sector decisions that would have occurred in any event. Rather, what is considered here are the additional/reduced costs and the additional/reduced health effects associated with a level of a standard and it's associated disposal method. Only these accurately reflect the real societal impact of a standard promulgated by EPA. For perspective, however, Table II also shows absolute costs and health effects parenthetically below the incrementals.

The incremental costs are also sufficient to provide the calculations of marginal cost-effectiveness which is the end-product of the impacts table. And again, the total costs are merely reflectiveof those costs that vary among the disposal options. They do not reflect such costs as storage and monitoring.

As Table II shows, it is expected that compliance with a 100 millirem standard could be achieved using a sanitary landfill facility with the waste in an as generated form. This would result in a total national saving over a 20 year period of $590 million as compared to the base case (current practice, 10CFR61), but would also cause an additional 160 health effects. A 50 millirem standard would require conventional shallow land disposal, would save $445 million relative to the base case, but would also cause an additional 28 health effects.

The analysis shows that a 25 millirem standard could be met by either conventional shallow land disposal with all classes of waste except class A being solidified or by the use of 10 CFR 61. Looking at the marginal cost-effectiveness for a 25 standard, the table shows that in moving from a 50 millirem standard to a 25 millirem standard, avoided health effects are purchased at approximately $16 million each. While this number is indicative of the cost-effectiveness of a 25 millirem standard, it is, in and of itself, insufficient to provide a true measure of the benefits of such a standard. Cost-effectiveness does not capture all of the policy objectives considered by the EPA when it chooses a standard (e.g. the value of reducing CPG risk). It can only be used to suggest which level of a standard best balances costs and population risk.

For a 5 millirem standard, the use of intermediate depth disposal with all forms except Class A being solidified is predicted. The incremental cost over the base case for the 20 year period would be about $344 million and would avoid approximately 10 health effects over the 10,000 year period of the analysis. And for the most stringent alternative standard, 2 millirem, it is predicted that the concrete canister technology would be used with the waste supercompacted and solidified. The associated incremental cost would be about $3.1 billion and would avoid 21 health effects over the 10,000 year period compared with the base case.

Again, it is important to remember that this discussion pertains only to the commercial sector. On the whole, we would expect that a 25 millirem standard, if applied to disposal of DOE waste, would cost an additional $135 million over the 20 year disposal period and avoid approximately 3 health effects over the 10,000 year period of the analysis. As previously mentioned, these numbers are dependent on the assumption that DOE LLW is similar in risk characteristics to commercial waste without its NARM component (7,8). Because it lacks a NARM component (which adds substantially to the resulting risk of disposal for the unsolidified options) not as much of a reduction in population risk is purchased when proceeding from conventional shallow land disposal to 10CFR61 technology. The marginal cost-effectiveness for DOE waste alone is therefore higher than that for commercial.

Attention is focused alone here on the cost of disposal options necessary to comply with different levels of a standard. Not accounted for are other minor costs of EPA's contemplated LLW standard such as predisposal requirements and groundwater protection. More significantly, the cost savings from a potential BRC criterion are not shown here even though they may more than offset the entire incremental cost of EPA's standard and significantly reduce the cost of such rulemaking to DOE. These savings are discussed in a paper presented at this Symposium by Holcomb (8).

IMPLEMENTATION CONSIDERATIONS

As mentioned, The cost and health impacts estimates are premised on a very important implementation assumption; that a single disposal method is used nationwide to meet a given standard and is constrained to meet that standard in the worst hydrogeologic setting. This is one of several implementation assumptions that can be posited with the resultant costs and health effects depending strongly upon the choice of this assumption. EPA will be looking at several methods of implementation in its economic impacts analysis.

The one mentioned and used to predict the cost and health impacts shown throughout this paper and in the impacts table is termed the national case because it assumes one method used nationwide with an implicit consideration of population health effects by limiting CPG dose. That is, by protecting the CPG it is assumed that the population is also protected. In utilizing this particular assumption to base our costs and health effects numbers on, much thought was given to the fact that NRC will have implementation authority for EPA's standard. The methodology of 10 CFR 61 suggests to EPA that they might favor, for some very good reasons, the use of uniform technology throughout the country and so we use this as our base case.

There are three other implementation assumptions that could be examined as logical possibilities from an economic perspective. One is the application of disposal technology within each hydrogeologic region sufficient only to meet the CPG millirem limit for that region, what is termed here as the regional case (with the upshot being that several different disposal methods may be used throughout the country to meet a given standard). The other is the combining of a CPG millirem limit with the explicit consideration of population health effects by taking into account the cost-effectiveness of using more stringent technology to further protect the population within a region, the regional cost-effective case.

A national cost-effective case may also be posited as the national implementation of one technology meeting not only the CPG standard but also taking into consideration the use of more stringent technology to be more protective of the population on a value per avoided health effect basis.

Efforts are being pursued to analyze the implications of these other implementation assumptions on EPA's costs and health effects estimates. It is expected that a full discussion of implementation will be presented in the published Economic Impact Assessment EPA is currently preparing on its LLW standard.

CONCLUSIONS

Two major conclusions can be drawn from the preceding analysis. The first is that the use of 10 CFR 61 as a disposal method meets a 25 millirem standard everywhere in the country as shown by our modeling and also appears to be the least-cost option to meet this standard (on a national implementation basis) within the resolving power of our analysis.

Secondly, while we have constrained ourselves here to use one disposal option combination on a nationwide basis for all hydrogeologic regions and waste streams within an NRC waste class for any given level of a standard and have based our cost and population health effects estimates on this, this constraint is based on an implementation assumption that is one of several that may be conjectured. An analysis is being performed to evaluate the significance of these other implementation options.

REFERENCES

1. Galpin, F.L. and Meyer, G.L., 1986, "Overview of EPA's Low-Level Radioactive Waste Standards Development Program, 86": Proceedings of 8th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, September 22-26, 1986, in Press, Denver, Colorado.

2. Gruhlke, J.M., "EPA Source Term for Low-Level Radioactive Waste Risk Assessment," U.S. Office of Radiation Programs, Environmental Protection Agency (draft), 1986.

3. U.S. Environmental Protection Agency, in Press, Proposed Low-Level Radioactive Waste Standards (40 CFR 193): Background Information Document: U.S. Environmental Protection Agency, Technical Report EPA 520/1-85, Washington, D.C.

4. Memorandum from Charles Queenan of Putnam, Hayes, and Bartlett, Inc. to Jim Gruhlke of U.S. EPA, Office of Radiation Programs, "Analysis of CPG and Population Risks From Regulated and Unregulated Disposal of LLW and NARM," January 24, 1986.

5. U.S. Nuclear Regulatory Commission, "Update of Part 61 Impacts Analysis Methodology," NUREG/CR-4370, January, 1986.

6. Bandrowski, M.S. and Gruhlke, J.M., 1986, "Inclusion of NARM in the LLW Standard": Proceedings of 8th Annual Participants' Information Meeting Meeting on DOE Low-Level Waste Management Program, Denver, Colorado,

7. Presentation by Putnam, Hayes, and Bartlett, Inc., for U.S. EPA, Office of Radiation Programs, "Economic Impacts of Alternative Low Level Waste Standards," August 18, 1986.

8. Holcomb, W.F. and Gruhlke, J.M., 1987, "EPA's LLW Standards Program: Below Regulatory Concern Criteria Development," Proceedings of the Waste Management Symposium '87, Tucson, Arizona, March 1-5, 1987, In Press, Tucson, Arizona .

9. Oertel, G.K., U.S. Department of Energy, Letter to T.A. McLaughlin, U.S. Environmental Protection Agency, June 11, 1982.

10. Welty, C., U.S. Department of Energy, Telephone conversation with G.L. Meyer, U.S. Environmental Protection Agency, January, 1986.

11. Hung, C.Y. *et al*, 1983, "Conceptual Designs and Cost Estimates for Land Disposal Systems Used in Development of EPA's Environmental Standards for Disposal of Low-Level Radioactive Waste": U.S. Department of Energy, Proceedings of 5th Annual Participants' Information Meeting for DOE Low-Level Waste Management Program, Denver, Colorado, August 30-September 1, 1983, CONF-8308106, Idaho Falls, ID.

12. Baird, R.D., Owen, D.H., and Rogers, V.C., "Engineering Cost Analyses for the Earth-mounded Concrete Bunker and Concrete Canister Disposal Methods and for the Engineering Surface Storage Method Applicable to Low-Level Waste Management," prepared for U.S. Environmental Protection Agency by Rogers and Associates Engineering Company, U.S. Environmental Protection Agency, Washington, D.C., 1986.

13. Memorandum from Micheal E. Burton of Putnam, Hayes, and Bartlett, Inc. to Elliot Foutes of U.S. EPA, Office of Radiation Programs, "Update of LLW Packaging, Processing, and Transportation Costs," February 11, 1986.

14. Alexander, P., Lindeman, R., Princehouse, S., and Saulnier, G., "Characterization of Land Disposal Alternatives for Low-Level Nuclear Wastes," prepared for U.S. Environmental Protection Agency by TRW Energy Development Group and Rogers and Associates Engineering Corporation, U.S. Environmental Protection Agency, Washington D.C., 1983.

15. U.S. Environmental Protection Agency, "PRESTO-EPA: A Low-Level Radioactive Waste Environmental Transport and Risk Assessment Code - Methodology and User's Manual," Prepared under Contract No. W-7405-eng-26, Interagency Agreement No. EPA-D--89-F-000-60, U.S. Environmental Protection Agency, Washington, D.C., April 1983.

16. Hung, C.Y., Meyer, G.L., and Rogers, V.C., 1983, "Use of PRESTO-EPA Model in Assessing Health Effects from Land Disposal of LLW to Support EPA's Environmental Standards": U.S. Department of Energy, Proceedings of 5th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, August 30, 1983, CONF-8308106, Idaho Falls, ID.

17. Meyer, G.L. and Hung, C.Y., 1981, "An Overview of EPA's Health Risk Assessment Model for the Shallow Land Disposal of LLW": Proceedings of an Interagency Workshop on Modeling and Low-Level Waste Management, Denver, Colorado, December 1-4, 1980, ORD-821, Oak Ridge National Laboratories, Oak Ridge, Tennessee.

18. "Summary of Unit Response Results," Putnam, Hayes, and Bartlett, Inc., July 22, 1986.

19. Bandrowski, M.S., Hung, C.Y., and Meyer, G.L., 1985, "Sensitivity Analyses of EPA's Codes for Assessing Potential Health Risks from Disposal of Low-Level Wastes": Proceedings of 7th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Las Vegas, Nevada, September 10-13, 1985, CONF-8509121, Las Vegas, Nevada.

20. Bandrowski, M.S., Hung, C.Y., Meyer, G.L., and Rogers, V.C., 1986, "Summary of EPA's Risk Assessment Results From the Analysis of Alternative Methods of Low-Level Waste Disposal," Proceedings of 8th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, September 22-26, 1986, In Press, Denver, Colorado.