United States
Environmental Protection
Agency

Office of
Radiation Programs
Washington DC 20460

EPA 520/1-82-024
December 1982

Radiation

EPA

Draft Regulatory Impact Analysis for 40 CFR 191:

Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes

EPA 520/1-82-024

DRAFT

REGULATORY IMPACT ANALYSIS

40 CFR Part 191

ENVIRONMENTAL STANDARDS FOR MANAGEMENT AND DISPOSAL OF SPENT NUCLEAR FUEL, HIGH-LEVEL AND TRANSURANIC RADIOACTIVE WASTES

DECEMBER 1982

U. S. ENVIRONMENTAL PROTECTION AGENCY

Office of Radiation Programs

CONTENTS

TABLES

FIGURES

Page

Chapter 1

INTRODUCTION AND SUMMARY

This Draft Regulatory Impact Analysis (RIA) addresses the requirements of Section 2 of Executive Order 12291. It reviews the projected costs associated with management and disposal of high-level radioactive waste, and it evaluates the potential effects of our environmental standards for disposal of these wastes (40 CFR Part 191)--as proposed for public review and comment on December 29, 1982 (47 FR 58196). The proposed standards are presented in the Appendix of this report, and they are explained in detail in the Draft Environmental Impact Statement (EIS) prepared for this action (EPA 82).

The situation regarding the disposal of high-level waste is unusual from a regulatory standpoint. In most cases, a regulation concerns an ongoing activity. Any modifications that the regulation causes in the activity may be considered to be costs that should be outweighed by the regulatory benefits. For high-level waste disposal, however, the appropriate regulations must be developed well before the activity to be regulated can even begin. Thus, the typical perspectives about balancing regulatory costs and benefits do not apply.

To investigate the potential impacts of this proposed action, we evaluated how the costs of high-level waste management and disposal might change due to alternative stringency levels for the numerical containment requirements of our standards--or due to alterations in our qualitative assurance requirements. Because there is no "baseline" program to consider, we could not quantify the costs and benefits of our proposed action compared to the consequences of no regulation.

The most important benefit of our action should be the assurance that these wastes will be disposed of with adequate protection of public health and the environment. This assurance, in turn, should allow the Federal program to proceed expeditiously to develop acceptable disposal methods at appropriate sites. It may be argued that a further benefit would be the resolution of a key issue that might lead to expanded commercial use of nuclear power. This would be a benefit if nuclear power has clear advantages, economic and otherwise, compared to alternative methods of generating electricity; however, we have not analyzed this issue.

The containment requirements in our environmental standards consist of limits on potential releases of radioactivity from a disposal system; these limits are to be used as overall design requirements. The containment requirements are stated in terms of projected releases for 10,000 years after disposal of the wastes. To judge the risks associated with these release limits, we have used generalized environmental pathway models to assess the potential health impacts of the releases that would be allowed by our standards (SMJ 82). However, calculations of these "residual risks" are clearly not reliable as absolute values, since projections of population distributions, ways of life, and human behavior over 10,000 years cannot be meaningful. Rather, these calculations are valuable only for understanding the relative "residual risks" from different sources of radiation exposure (such as risks from different disposal system designs, or risks from natural ore bodies).

For the containment requirements we have proposed, the residual risks projected by these models would be less than 1,000 premature deaths from cancer over the 10,000 year period, an average of one premature death every ten years. To judge the effects on disposal costs of changing this level of protection, we also compared containment requirements corresponding to residual risk values of: 100, 1000, 5000, and 10,000 premature deaths over the 10,000 year period. We chose this range of residual risks because it appears to represent the range of performance that may be expected of mined geologic repositories.

To do this analysis, we evaluated the long-term performance of generic models of geologic repositories in three different geologic media: bedded salt, granite, and basalt. We did the analysis in two steps:

First, we used our performance projections (SMC 82) to assess the quality of the engineering controls that would be needed in each of the three model repositories to meet each of the four different levels of protection. In doing so, we encountered the problem that development of specific engineered barriers (e.g., waste forms and canisters) has not yet progressed far enough to clearly associate the costs of manufacturing these engineered barriers with their performance levels. Thus, we had to make some rather speculative judgements to associate disposal costs with alternative stringency levels. The results of this analysis are displayed in Figure 1-1.

Second, we tried to allow for the possible effect of alternative stringency levels on site selection. This is particularly relevant because our analyses indicate that the most important part of the protection offered by a mined geologic repository comes from the hydrological and geochemical characteristics of the site itself. The costs of using a "good" site rather than a "bad" site (within the same type of geologic media) do not involve differences in construction cost. Instead, they involve the difficulty of finding a site that is "good enough." Since there are so few data on site characterization, we have no good basis for judging how many sites might have to be studied to meet different levels of protection. However, we did made some assumptions about how site selection costs might increase in order to meet more stringent standards. We then combined these assumptions with our evaluations of the variations in engineered barrier costs to arrive at our second set of disposal cost estimates. The results from this analysis are shown in Figure 1-2.

The results of these assessments of disposal costs and alternative stringency levels indicate that the costs are not very sensitive to different levels of protection, particularly for the geologic media

FIGURE 1-1: VARIATIONS IN WASTE MANAGEMENT COST vs. LEVEL OF PROTECTION

(Engineering Barrier Costs Only)

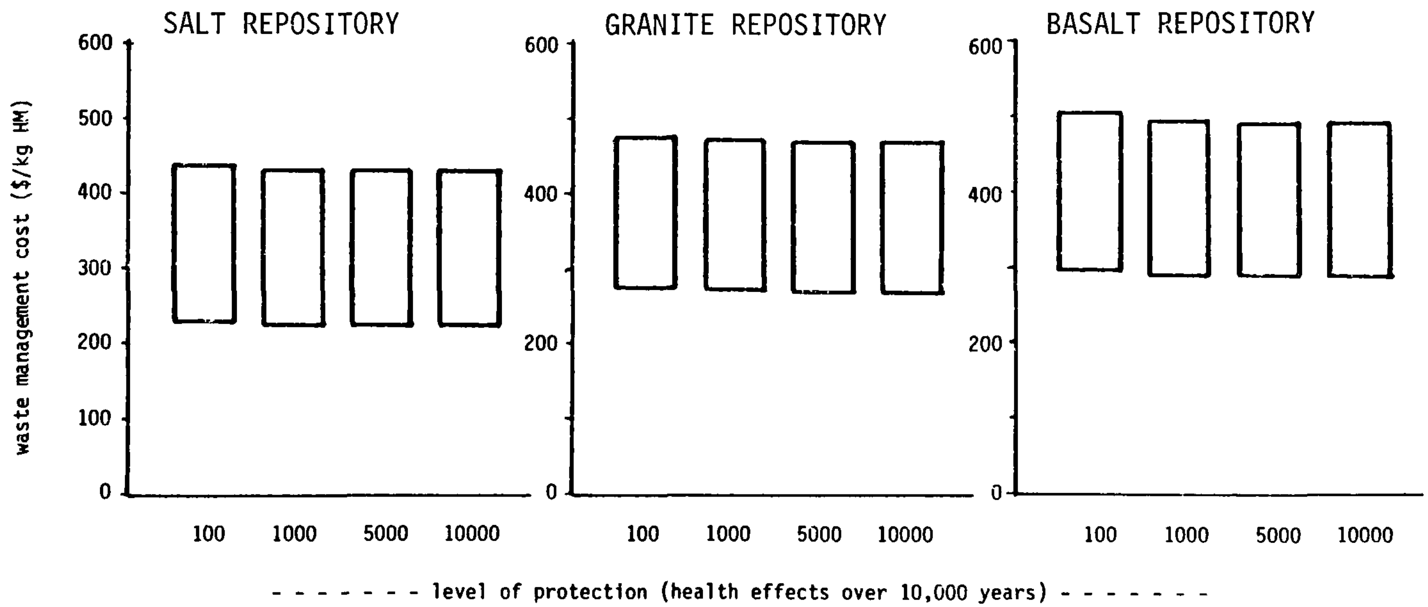
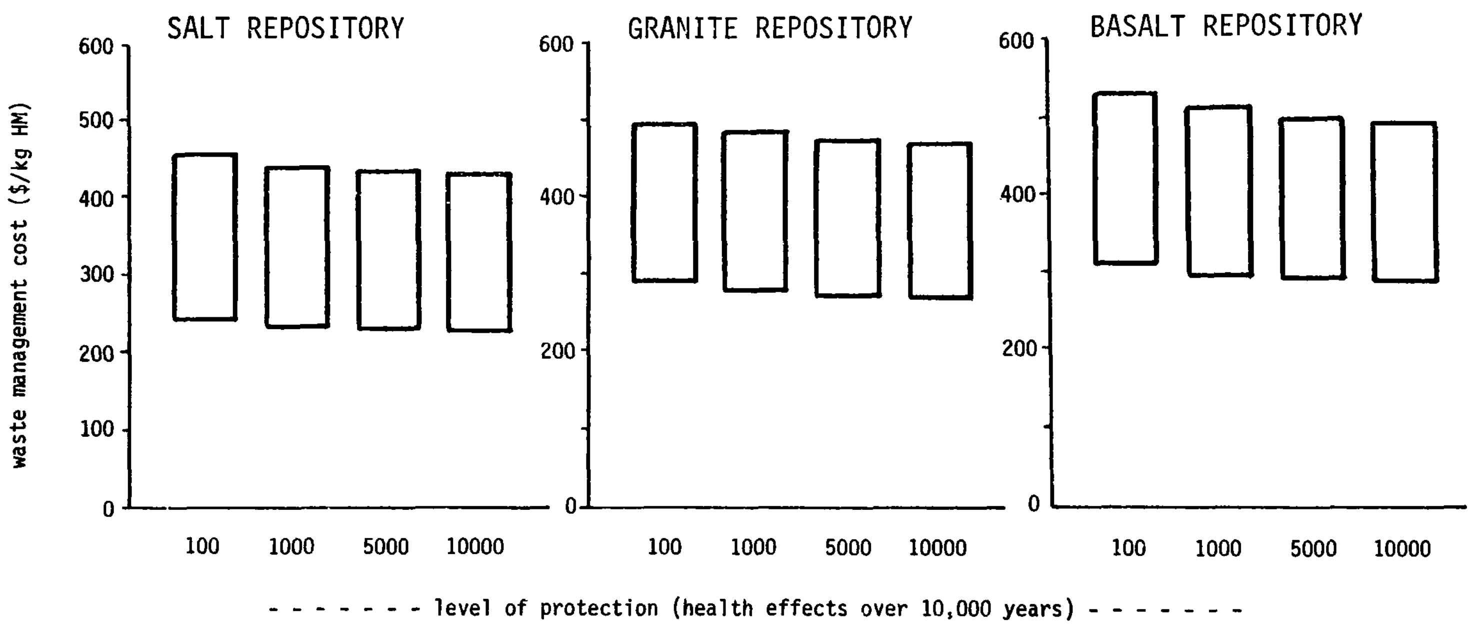


FIGURE 1-2: VARIATIONS IN WASTE MANAGEMENT COST vs. LEVEL OF PROTECTION

(Engineering Barrier Costs and Site Selection Costs)



(bedded salt and granite) that are better at reducing long-term risks. Even when we hypothesize increased site selection costs due to more stringent levels, the difference in costs for different levels are much smaller than the overall uncertainties in waste management costs. For example, consider the increased costs of complying with the release limits we have proposed, rather than release limits ten times less stringent. The potential increase ranges from zero to 50 million (1981) dollars per year. For comparison, the total costs of high-level waste management and disposal (independent of our action) have been estimated as between 700 million and almost 1.5 billion (1981) dollars per year. Electrical utility revenues were about 100 billion dollars in 1980.

These analyses--while indicating that disposal costs appear to be relatively insensitive to differences in the level of protection--do not provide a way to determine the acceptability of the residual risks from a societal perspective, nor do they indicate a level of protection that is preferable from a balancing of costs and benefits. One possible approach to balancing costs and benefits would be to judge the cost per life saved by different levels of protection, perhaps taking into account some method of discounting costs and benefits. However, our calculations of residual risks are not reliable as absolute values. Thus, we have no meaningful way to calculate an absolute value of the cost per life saved by different levels of protection.

In the absence of the ability to make meaningful cost and benefit comparisons, we have used other tests of economic feasibility and acceptability of risk to judge the appropriateness of the level of protection we have proposed. As discussed above, setting the release limits at the level we chose--as opposed to a level ten times less or ten times more stringent--appears to cause only very minor effects on the costs of high-level waste disposal. To judge the acceptability of the remaining long-term risk, we considered the risks that would otherwise be caused if the uranium ore used to produce the wastes had not been mined. The magnitude of the risks from these unmined ore bodies is very uncertain due, in part, to the wide variety of settings in which uranium ore is found--many of which are closer to the surface than a geologic repository would be. Using the same generalized environmental pathway models that were used to assess the risks from our models of geologic repositories, the risks from a comparable amount of unmined uranium ore are estimated to range from a few hundred to more than one million health effects over 10,000 years (WI 80). The lower end of this range is roughly equal to the residual risk associated with our proposed release limits. Thus, the upper limit of the risk that our standards would allow from the disposal of high-level wastes appears to pose a threat very close to the minimal risk posed by nature, had the uranium ore never been mined and the high-level wastes never been generated.

The assurance requirements of our proposed standards provide seven qualitative criteria which should provide confidence that our containment requirements will be met in spite of the uncertainties inherent in disposing of wastes that must be isolated for a very long time. The specific provisions of these assurance requirements are described in the Appendix to this report. Only three of the criteria have a significant potential to increase the costs of high-level waste disposal. These are:

Criterion 2, which calls for disposal systems to keep radioactive releases as small as reasonably achievable;

Criterion 3, which calls for disposal systems to use multiple barriers, both engineered and natural; and

Criterion 4, which restricts reliance on active institutional controls to a reasonable period after disposal (e.g., a few hundred years).

Each of these three criteria might have the effect of requiring better engineered barriers than would otherwise be needed to meet our containment requirements. This would be particularly true for a repository sited in a relatively good geologic media (such as our generic models for bedded salt or granite). However, even if no engineered barriers at all appeared to be needed for long-term protection after disposal, fairly protective canisters and waste forms would be needed for other phases of waste management, such as transportation to and emplacement in a repository. Therefore, we believe that these criteria would require--at most--only moderate improvements in waste form performance, and we judged that the impact that these improvements might have on disposal costs should be less than 10 million (1981) dollars per year. Since this impact concerns improvements to engineered barriers, the potential cost increase would be duplicative of any engineered barrier impacts caused by our containment requirements. Thus, the potential cost effects of our containment and assurance requirements should generally not be added together. (For some unusual possibilities, adding the effects of the two sets of requirements might be appropriate, but these possibilities would tend to involve relatively small impacts.)

The analyses described in this report are intended to provide a realistic estimate of the costs of the various regulatory alternatives we considered. In an earlier report (LE 80), we took a different approach--one that ultimately did not prove useful for evaluating the regulatory impacts of this action. In that effort, we were trying to judge how large the cost impacts of our action might be if our standards required major alternations in plans for disposal of high-level waste; and we made several very conservative assumptions to estimate the upper bound of such additional costs. (For example, we assumed a "baseline" program of disposal in salt, the cheapest geologic medium, and then assumed that our action might require use of the most expensive medium - even though our performance assessments indicate exactly the opposite. Also, there is no longer a justification to consider salt as the "baseline" program.) Accordingly, in the earlier report, we discussed possible cost impacts of our action that are much larger than those described here. Although we have retained some of the analytical framework we assembled before, we do not believe that the earlier report's quantitative findings are valid for the type of analysis called for by Executive Order 12291.

Chapter 2

REGULATORY GOALS

The decision to develop these proposed standards was an administrative action taken by EPA and was not mandated by law. We were directed to prepare standards as part of President Ford's Nuclear Waste Management Plan on October 27, 1976. President Carter established an Interagency Review Group (IRG) on Waste Management in March 1978 to review existing policies where necessary. The IRG recommended that EPA set standards for nuclear waste management and disposal activities and accelerate its programs to do so. In making its recommendations, the IRG noted the following about the public comment on its draft report (IRG 79):

> "Comment from both the industrial sector and the environmental community urged the acceleration of EPA standards particularly to instill confidence that proper protection of the public's health and safety is being provided. They expressed the concern that early standards are essential to permit the waste management program to proceed expeditiously."

President Carter approved the IRG recommendation as part of his Program on Radioactive Waste Management announced on February 12, 1980. The Nuclear Regulatory Commission (NRC) has best described the expected goal of our standards (NRC 80):

> "...(EPA's) standards represent a broad social consensus concerning the amount of radioactive materials and levels of radioactivity in the general environment that are compatible with protection of the health and safety of the public."

Thus, we have two interrelated regulatory goals in taking this action:

(1) to provide quantitative containment requirements that will limit long-term radioactive releases from high-level waste disposal systems to levels which are reasonably achievable, very small, and adequate to protect the health and safety of the public.

(2) to provide qualitative assurance requirements that will compensate for the uncertainties inherent in trying to design systems that must meet these containment requirements for a very long time.

We believe that accomplishing these two goals will help to instill the confidence needed "to permit the waste management program to proceed expeditiously" in order to resolve a long-standing issue.

Chapter 3

STATUS OF NATIONAL PROGRAM

In 1976, also as part of President Ford's Nuclear Waste Management Plan, the Energy Research and Development Administration (ERDA) began the National Waste Terminal Storage (NWTS) program to develop technology and provide facilities for the permanant disposal of high-level waste. As part of this expanded initiative, the Department of Energy (DOE)--successor to ERDA--prepared a generic environmental impact statement (GEIS) concerning selection of a strategy for disposal of commercially generated high-level waste. This GEIS, which evaluated a variety of different disposal methods, was issued in draft form for public review and comment and was published as a final EIS in October 1980.

On May 14, 1981, DOE issued a Record of Decision (46 FR 26677) based upon the information developed through its GEIS process. This decision was:

> "(1) to adopt a strategy to develop mined geologic repositories for disposal of commercially-generated high-level and transuranic wastes (while continuing to examine subseabed and very deep hole disposal as potential back up technologies) and (2) to conduct a research and development program to develop repositories and the necessary technology to ensure the safe long-term containment and isolation of these wastes."

This decision to emphasize mined repositories was based on DOE's:

> ". . . commitment to the early and successful solution of the Nation's nuclear waste disposal problem so that the viability of nuclear energy as a future energy source for America can be maintained."

DOE also expects this decision to:

> ". . . save money by focusing Federal funds on the further development of the most advanced disposal technique."

Now focused on disposal in mined geologic respositories, the overall goal of the DOE program is to provide the United States with its first licensed, fully operational repository. On January 7, 1983, President Reagan signed the Nuclear Waste Policy Act of 1982 (Public Law 97-425)--which was passsed by Congress, after lengthy consideration, in December 1982. This Act establishes a series of milestones for the national program, oriented towards a January 1, 1989 objective for a Nuclear Regulatory Commission decision on DOE's first application for a construction authorization for a mined geologic repository.

The NRC is responsible for licensing and regulating the geologic repositories that will be built and operated by DOE, and, in doing so, NRC is responsible for implementing our environmental standards.
On July 8, 1981, NRC proposed the technical criteria it plans to use in regulating the disposal of high-level wastes in geologic repositories (46 FR 35280). When finalized, these requirements will become part of 10 CFR Part 60. These technical criteria include several specifications for waste package and site characteristics. The two criteria that involve factors considered in our regulatory impact analysis of 40 CFR 191 are the two that embody NRC's multiple engineered barrier approach to repository design: (1) the performance of the engineered system (waste package and underground facility) following permanant closure of a repository

is specified to require containment of the wastes within the waste package for at least 1,000 years following closure, and (2) after the first 1,000 years, the annual release rate of any radionuclide from the engineered system into the geologic setting is specified to be no more than one part in 100,000 (10^{-5}) at any time. These two specifications, which affect canister lifetime and waste form release rate, are the ones that are most likely to have significant effects on disposal costs.

Chapter 4

BENEFITS OF PROPOSED ACTION

We believe that these proposed standards will provide adequate long-term protection of public health and the environment, and we expect them to provide a high-degree of confidence that this protection can be attained. In turn, this assurance should allow the national high-level waste management program to proceed with the key steps needed to develop and demonstrate a disposal system. In the context of the country's current strategy to focus on mined geologic repositories, these steps involve identification, extensive examination, and comparison of potential repository sites. To date, this part of the program has been substantially delayed by non-technical problems, including a number of state laws which restrict or prohibit disposal of high-level waste.

While we can identify this qualitative contribution, we cannot quantify the benefits of our proposed standards compared to the consequences of having no regulation. We did not attempt to calculate how much additional protection the containment requirements provide, because we cannot specify how these wastes would have been disposed of without our action. However, there are three qualitative benefits that the containment requirements clearly provide. First, they tell system designers the most important objectives for environmental protection. For example, a system designed to limit releases for 1,000 years could rely primarily on engineered barriers, whereas a system designed to retain wastes for 10,000 years also requires good geological and hydrological characteristics at the site chosen. Second, they require a comprehensive assessment of total system performance to assure that the containment requirements would not be exceeded. Finally, they can provide confidence that good disposal systems can keep the risks to present and future generations very small.

The problem with quantifying the benefits of our qualitative assurance requirements is quite different than that associated with assessing the benefits of the containment requirements--and it would not be solved even by specification of a "baseline" program. These seven criteria are intended to guard against a variety of uncertainties that are inherent in the disposal of these long-lived wastes. Quantifying their benefits is not feasible, since we cannot calculate the risks we might be preventing due to things we may not be able to anticipate. Two examples illustrate this point:

(1) One of our assurance requirements calls for use of different, multiple barriers to guard against releases due to unanticipated failure of one or more barriers. The amount of risk prevented depends upon how (any how many) barriers fail, and our inability to be certain of this is exactly why we established this requirement in the first place.

(2) Another of our assurance requirements states that the wastes shall be recoverable for a reasonable period after disposal, in case future information indicates they should be handled in some other way. But since we cannot specify what this future information might be, we cannot quantify the benefits of keeping this option available.

In spite of our inability to quantify these benefits, the necessary confidence in achieving the long-term public health and environmental protection required by our containment requirements is a substantial benefit of our assurance requirements--the two sets of requirements are essential complements to each other. Neither the containment requirements nor the assurance requirements, by themselves, can accomplish our regulatory goals.

Chapter 5

COSTS OF WASTE DISPOSAL

There have been many studies of the costs of high-level waste management and disposal. However, there are still substantial uncertainties because disposal sites have not been selected, operational facilities have not been built, and some of the technologies for engineered barriers have not been fully developed and tested. Table 5-1 shows the range of costs that we considered in this analysis. These estimates were taken from three different sources (LE 80, ADL 79, and DOE 80) and were generally chosen so as to minimize, rather than maximize the range of estimates shown for each cost element. Unless otherwise stated, all costs are in 1981 dollars, and have been calculated by using the following inflation factors, which are based on the Department of Commerce Composite Construction Cost Index (SA 81): 1.50 for converting 1977 to 1981 dollars; 1.34 for 1978 to 1981 dollars; and 1.17 for 1979 to 1981 dollars.

The following paragraphs discuss the cost estimates for each item, with particular attention to the four elements which might be affected by our disposal standards. Where recently available information is relevant to these estimates, it is also included. In all cases, we discuss the costs in terms of dollars per kilogram of heavy metal (uranium or plutonium) inserted as fuel into a commercial reactor ($/kg HM). This is a commonly used unit of cost for waste management and disposal, and it allows comparisons of the cost of disposing of spent fuel or different

Table 5-1

Total Costs of Waste Management (1981 dollars)

cost element	$/kg HM	
STORAGE	90 - 230	
TRANSPORTATION	17 - 41	
ENCAPSULATION (Canister)	11 - 30	*
WASTE FORM	12 - 24	*
REPOSITORY CONSTRUCTION AND OPERATION	66 - 131	*
RESEARCH AND DEVELOPMENT	11 - 40	*
GOVERNMENT OVERHEAD	3 - 10	
DECOMMISSIONING	14 - 17	
TOTAL	224 - 523	

* Cost elements which might be affected by proposed standards:

			$/kg HM
Assumptions about canister costs:	"very good"	=	20 - 30
	"good"	=	14 - 23
	"minimum"	=	11 - 20
Assumptions about waste form costs:	"very good"	=	18 - 24
	"good"	=	16 - 22
	"fair"	=	14 - 20
	"minimum"	=	12 - 18
Assumptions about repository construction costs:	salt	=	66 - 73
	granite	=	109 -110
	basalt	=	123 -131
Assumed variation of research and development costs with alternative stringency levels: (health effects over 10,000 years)	10,000	=	11 - 20
	5,000	=	14 - 24
	1,000	=	17 - 30
	100	=	22 - 40

forms of high-level waste from reprocessing plants. When used to describe disposal after reprocessing, of course, the unit $/kg HM does not mean that the heavy metal itself is being disposed of--since the purpose of reprocessing spent fuel is to recover and reuse the unfissioned uranium and plutonium.

5.1 Storage

Our previous study (LE 80) identified a wide range of cost estimates for spent fuel storage: from $15 to $200 per kg HM in either 1977 or 1978 dollars. The higher end of this range corresponds to significant use of away-from-reactor (AFR) storage, which is more expensive than reactor-site storage. The $15/kg HM estimate appears to be too low, with most estimates of reactor-site storage clustering around $60 to $80/kg HM in 1977 or 1978 dollars (LE 80). For this analysis we chose a range of $60 to $150/kg HM (1977 dollars), allowing for some use of AFR storage, and adjusted the estimate to $90-230/kg HM in 1981 dollars.

5.2 Transportation

Two shipments are involved in a fuel cycle that includes reprocessing: one from the spent fuel storage site to the reprocessing plant and another from the reprocessing plant to the repository. Arthur D. Little, Inc. (ADL) estimated the costs of these two shipments to be $8-18/kg HM and $3-$8/kg HM, respectively, with both estimates in 1977 dollars. To develop the estimate in Table 5-1, we added the costs for both shipments and converted to 1981 dollars, for a cost range of $17-41/kg HM (1981 dollars).

5.3 Encapsulation (Canister)

The encapsulation cost element is the first of the four that may be affected by our disposal standards. Unlike the storage or transportation categories, the type of canister used to contain the wastes can affect the long-term performance of a repository. Thus, we estimated the costs of using canisters of three different qualities. These three categories are described in Table 5-2.

To develop these cost estimates, we first considered ADL's projections for the costs of spent fuel canisters (ADL 79), but we substituted the lower material costs that would be associated with the smaller canisters used for reprocessed waste. We then assumed that the material for stainless steel canisters would cost about three times as much as carbon steel, and that titanium would cost at least seven times as much as carbon steel. This resulted in facility, operating and maintenance costs of \$6-12/kg HM, and materials costs of \$1/kg HM (carbon steel), \$3/kg HM (stainless steel), and \$7-8/kg HM (titanium), with all of these figures in 1977 dollars. Combining these and inflating to 1981 dollars resulted in the cost estimates shown in Table 5-2.

It must be noted that the association of canister performance with canister material (and cost) is based upon quite limited information (ADL 79), and includes considerable engineering judgement. However, preliminary information from DOE design studies of long-lived canisters indicate costs that are roughly comparable to those of Table 5-2 (VI 81).

Table 5-2

Performance Categories and Assumed Costs for Waste Canisters

"very good"	=	canister that would last several thousand years; titanium or even KBS-style copper canisters would be required. Estimated engineering cost = $ 20-30/kg HM.

(NOTE: NRC's proposed 10 CFR Part 60 would require a waste pacakage lifetime of at least 1000 years.)

"good"	=	canister that would last several hundred years; in hard rock repositories, stainless steel canisters would probably be adequate. Estimated engineering cost = $ 14-23/kg HM
"minimum"	=	canister that would last at least several decades to a few hundred years in hard rock repositories--might only last through operational lifetime for salt repositories; carbon steel and overpack construction assumed. Estimated engineering cost = $ 11-20/kg HM.

5.4 Waste Form

The physical and chemical properties of the solidified high-level waste from reprocessing also affect the long-term performance of a repository. However, we are not aware of any published studies which relate the waste form behavior (in terms of resistance to releasing radioactivity) to the production costs of different waste forms. In this respect, the costs for different waste forms are more uncertain than the costs for canisters.

For this analysis, we postulated costs for different quality waste forms, as shown in Table 5-3. The Arthur D. Little, Inc. study (ADL 79), DOE's GEIS (DOE 80), and another recent study (JA 81) conclude that the costs of different waste forms do not vary substantially from one type to another, and the variation that is observed is generally less than the overall uncertainty in the cost of any specific waste form. However, preliminary results from newer DOE studies indicate that waste form costs may increase substantially if relatively sophisticated processes are needed to provide very high quality waste forms (WA 81). In addition to these qualitative observations, the quantitative cost information shown in Table 5-4 is available.

Based on this information, and the observation that it should generally cost more to make better quality waste forms, we made the cost and performance judgements shown in Table 5-3. As before, the cost estimates were converted to 1981 dollars.

Table 5-3

Performance Categories and Assumed Costs for Waste Forms

"very good"	=	10^{-6} - 10^{-5} parts per year (ppy) leach rate; may be attainable if ongoing technology development programs are successful. Estimated engineering cost = $ 18-24/kg HM.

(NOTE: NRC's proposed 10 CFR Part 60 would require a waste form release rate no worse than 10^{-5} ppy.)

"good"	=	about 10^{-4} ppy leach rate; appears attainable by glass technologies already developed. Estimated engineering cost = $ 16-22/kg HM.
"fair"	=	about 10^{-3} ppy leach rate; clearly attainable by glass technologies, might be attainable by even simpler waste forms. Estimated engineering cost = $ 14-20/kg HM.
"minimum"	=	about 10^{-2} ppy leach rate; attainable by simple calcine waste forms--the minimum probably needed for transportation safety Estimated engineering cost = $ 12-18/kg HM.

[NOTE: Available data indicates that cost variations between the different waste forms now being developed is only about $2-4/kg HM (less than one per cent of high-level waste disposal costs). Relative values shown above are assignments from the range of costs shown below, increased somewhat to reflect DOE comments.]

Table 5-4

Cost Information on Waste Forms

Cost	Source	Comment
$8-15/kg HM (1977 dollars)	ADL 79	range excludes a low value of $4/kg HM
$10-13/kg HM (1978 dollars)	DOE 80	
$16-18/kg HM (1979 dollars)	JA 81	considered some relatively sophisticated metal-matrix waste forms.

5.5 Repository Construction and Operation

We took our cost estimates for repository construction and operation from DOE's GEIS (DOE 80). We considered three different geologic media (salt, granite, and basalt), and we inflated the GEIS's 1978 dollars to 1981 dollars. The range of costs for each medium results from the repository being used either for high-level waste from reprocessing or for spent fuel, with the latter being slightly more expensive per kg HM. These cost estimates are shown in Table 5-5.

5.6 Research and Development

Our basic estimate for research and development costs, \$8-14/kg HM (1978 dollars), was developed in our earlier report (LE 80). Many of these costs are associated with surveying, identifying and characterizing appropriate sites for a repository--these are identified as "site selection" costs. It will be shown in the next section that much of the protection provided by a repository comes from the characteristics of the particular disposal site (e.g., appropriate geochemistry), although engineered barriers can compensate for some site deficiencies. Therefore, the magnitude of the research and development costs can be significantly affected by the level of protection we choose for our containment requirements. For example, current plans call for DOE to investigate several sites in detail before selecting one for the first repository. If our standards were stringent enough to prevent any of these first sites from being acceptable, then the national program could be significantly delayed and site selection costs would probably increase substantially.

Table 5-5

Repository Construction Costs (DOE 80)

	$/kg HM
salt	66 - 73
granite	109 - 110
basalt	123 - 131

However, until much more information is available about proposed sites, the magnitude of site selection costs cannot be quantitatively associated with different levels of protection. Nevertheless, to provide some perspective on the potential impacts of changes in site selection costs, we postulated a set of research and development costs that increase with increasingly stringent levels of protection. Table 5-1 shows these costs, with the cost for the least stringent level (10,000 health effects) being our earlier research and development estimate of $8-14/kg HM (1978 dollars) adjusted to 1981 dollars.

5.7 Government Overhead and Decommissioning

Government overhead is defined as all expenses to the Government that are not related to research and development and are not directly associated with another cost element. Decommissioning costs are those associated with final sealing of a repository, decontaminating and dismantling surface facilities, and permanently marking the site of the repository. The estimated costs for these two elements were developed in our earlier report (LE 80) as $2-7/kg HM and $10-12/kg HM (1978 dollars), respectively. Neither element is likely to be affected by the level of stringency chosen for our standards. The estimates shown in Table 5-1 are the same as our earlier ones, but are recalculated in terms of 1981 dollars.

Chapter 6

DIFFERENT LEVELS OF PROTECTION

A number of considerations are applicable to the selection of the level of protection that should be provided by our proposed environmental standards. In this Chapter, we describe several assessments relevant to this selection, including: (a) the long-term performance of different repository designs, using various sets of engineering controls and geologic media; (b) the relative incidence over time of the residual risks associated with different levels of protection; (c) the correlations between repository performance and cost relative to four alternative levels of protection: 100, 1000, 5000, and 10,000 excess health effects over 10,000 years; (d) the economic impacts of variations in the cost of high-level waste management and disposal; and (e) an evaluation of the long-term risks that future generations would be subjected to if the uranium ore used in creating these wastes had not been mined. We then discuss how we used these assessments to select our proposed containment requirements. Throughout this Chapter, we often refer to residual risks in terms of excess health effects over 10,000 years. However, the reader should recall the caveats regarding these assessments discussed in Chapter 1.

6.1 Long-Term Performance Assessments

We analyzed the long-term performance of mined geologic repositories by considering many combinations of waste canister lifetime, waste form release rate, geologic media, groundwater geochemistry, and geologic factors that may vary from site to site (SMC 82). To do this, we used generic models of repository sites and designs. Our analyses are not necessarily applicable to any specific disposal site. However, we believe: (1) that they indicate the relative importance of the various parts of a repository system and (2) that they provide a general understanding of the protection achievable by different combinations of engineered and natural barriers.

Our performance assessments considered the excess premature cancers ("health effects") that might occur during the first 10,000 years after disposal. We selected 10,000 years as the assessment period for two reasons:

(1) It is long enough for releases through groundwater to reach the environment. If we had selected a shorter time (such as 1000 years) our estimates of harm could be deceptively low because groundwater could take at least 1,000 years to reach the environment at a well-chosen site. Choosing 10,000 years for assessment encourages selection of sites where the geochemical properties of the rock formations can significantly reduce releases of radioactivity through groundwater.

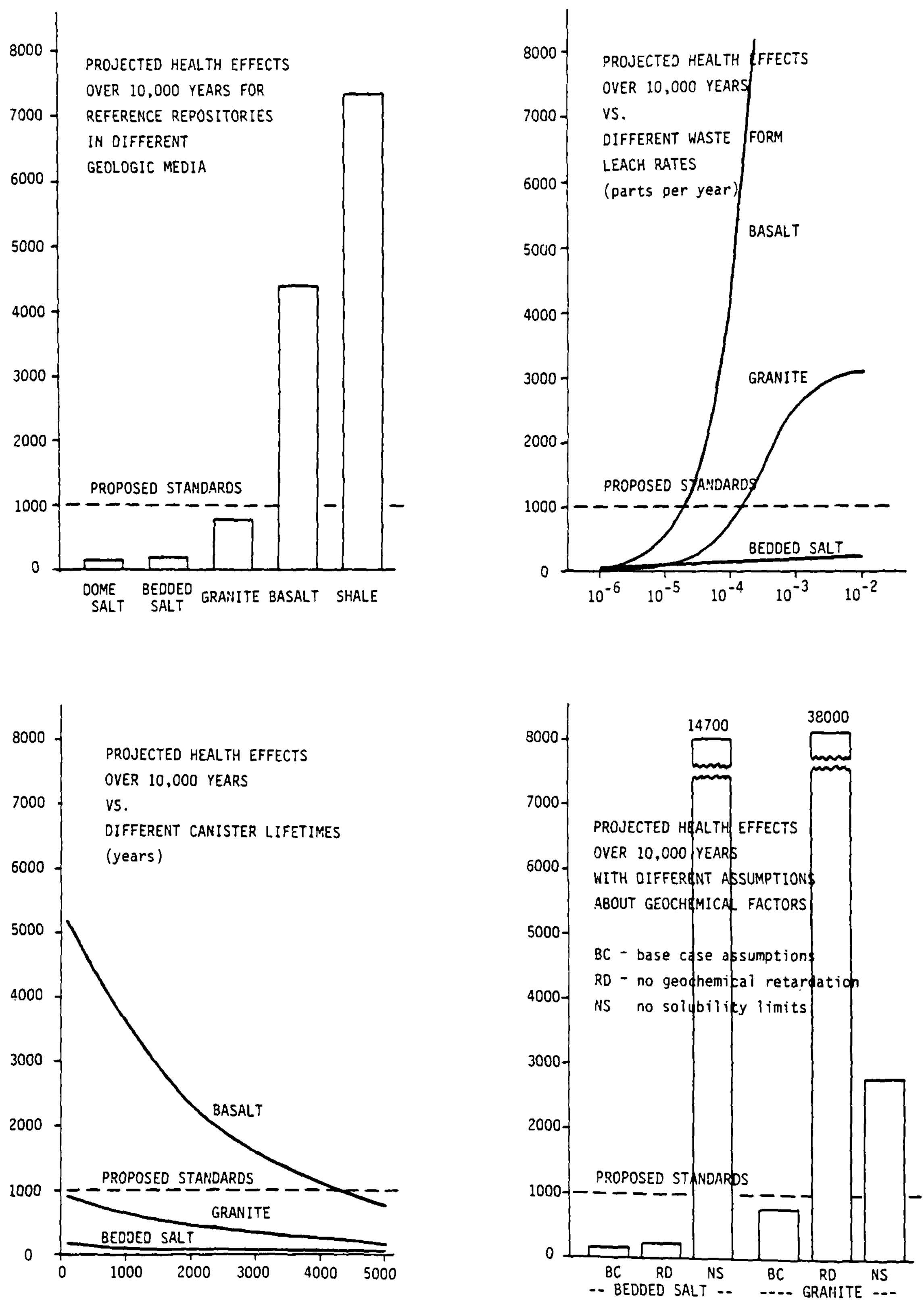
(2) It is short enough that the likelihood and characteristics of geologic events which might disrupt the repository are reasonably predictable over the period. Major geologic changes, such as development of a faulting system or a volcanic region, take much longer than 10,000 years.

Our assessments considered five different geologic media: bedded salt, salt domes, granite, basalt and shale. This regulatory analysis focuses on only three of these (bedded salt, granite, and basalt) because the results for domed salt are very similar to those for bedded salt and the results for shale are similar to those for basalt. Figure 6-1 summarizes the results we obtained by varying canister lifetime, waste form leach rate, and site geochemistry while holding the other factors constant. Unless otherwise indicated, the canister lifetime used was 500 years (100 years in salt), the waste form leach rate was 10^{-4} parts per year, and the radionuclide solubility limits and retardation factors were those indicated in the detailed report of these analyses (SMC 82).

Several broad conclusions can be drawn from these performance assessments:

First, major changes in the geochemistry at a site can affect long-term risks much more than major changes in the engineered barriers. For example, neglecting geochemical retardation for a granite repository increases the consequences from about 800 health effects to 38,000. (This is the "RD" case in Figure 6-1; the "NS" case assumes that solubility is never limited for any radionuclide, while the "BC" case represents desirable site characteristics--which include both geochemical retardation and solubility limits.) In comparison, assuming that the waste form dissolves very quickly raises risks to a little more than 3000, while assuming a zero lifetime for the waste canister increases risks only

FIGURE 6-1: THE LEVEL OF PROTECTION



to about 1000. Thus, it appears that efforts to identify a repository site with appropriate characteristics can have greater benefits than efforts to improve engineering controls.

Second, comparing the two types of engineering controls, variations of waste form leach rate consistently have more effect on long-term risks than variations of canister lifetime. Improvements in waste form appear to provide more benefits than improvements in waste canisters.

Third, good engineering controls, particularly good waste forms, can overcome poor site characteristics. Our generic model of a basalt repository assumes that relatively large amounts of groundwater are available to dissolve and transport waste. In spite of this disadvantage, our basalt model can achieve risks comparable to those at the low end of the range for our granite model _if_ the waste form used with basalt is about an order of magnitude better than that used with granite.

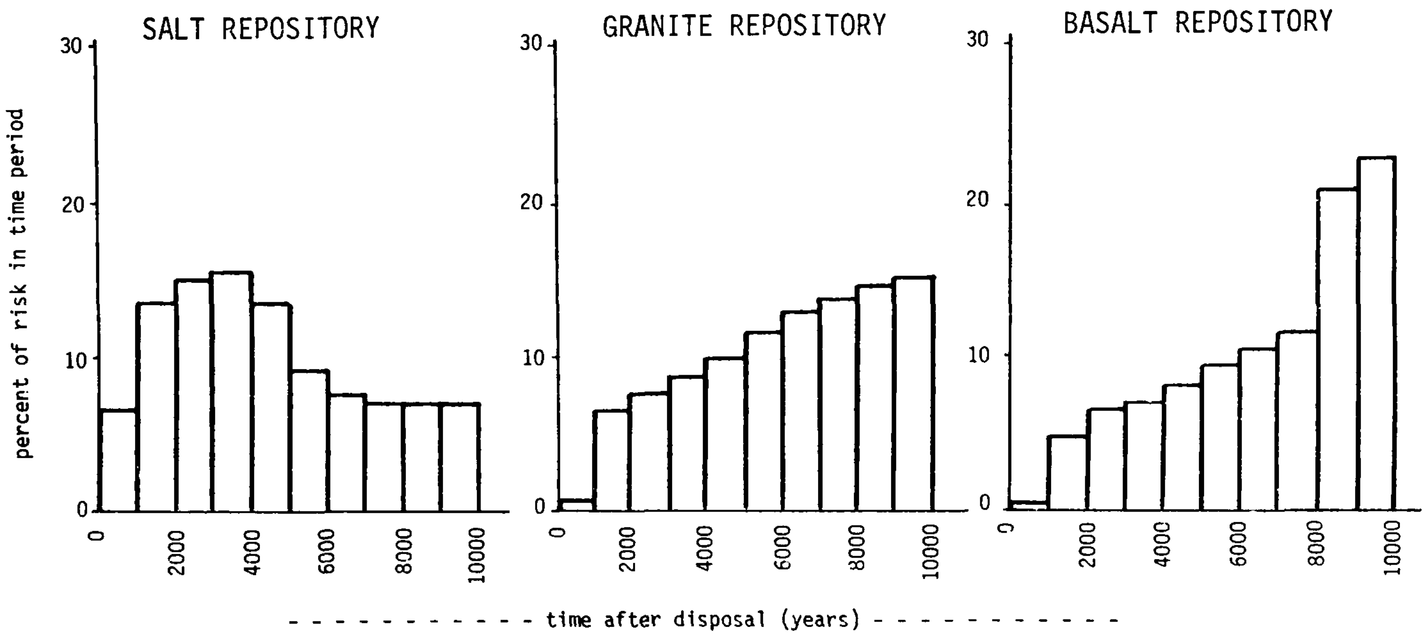
Finally, sites with very good geologic and hydrologic characteristics might not need any engineering controls to meet very low risk levels. For example, the projected impact from our bedded salt model--which includes very little groundwater--does not exceed about 200 health effects even if the waste form dissolves very quickly and the canisters have zero lifetime (provided that the advantageous site geochemistry and hydrology perform as expected).

6.2 Benefits of Different Levels of Protection

In the simplest sense, the benefits of any level of protection that is more stringent than another level are the potential deaths averted by the more stringent level. (For example, the difference between setting standards with a residual risk of 1,000 health effects over 10,000 years, versus setting standards ten times less stringent, can be considered to be the 9,000 health effects avoided over 10,000 years.) However, the benefits of one level of protection compared to another--with regard to the regulatory goals we identify in Chapter 2--actually involve a variety of broader societal perspectives.

One perspective that may be considered is how the risks allowed by the standards might occur in the future. Figure 6-2 indicates the relative incidence of the residual risks over time from three model repositories that would comply with our proposed containment requirements. [Specifically, these three models are: (1) our basic model for bedded salt, which presents residual risks of about 200 health effects over 10,000 years, (2) our basic model for granite, with about 700 health effects, and (3) a model for basalt with improved engineering controls that bring the risks down to about 700 health effects.] All three of these models would meet the release limits associated with 1,000 health effects. Particularly for the granite and basalt models, relatively little of the residual risk occurs in the first 1,000 years.

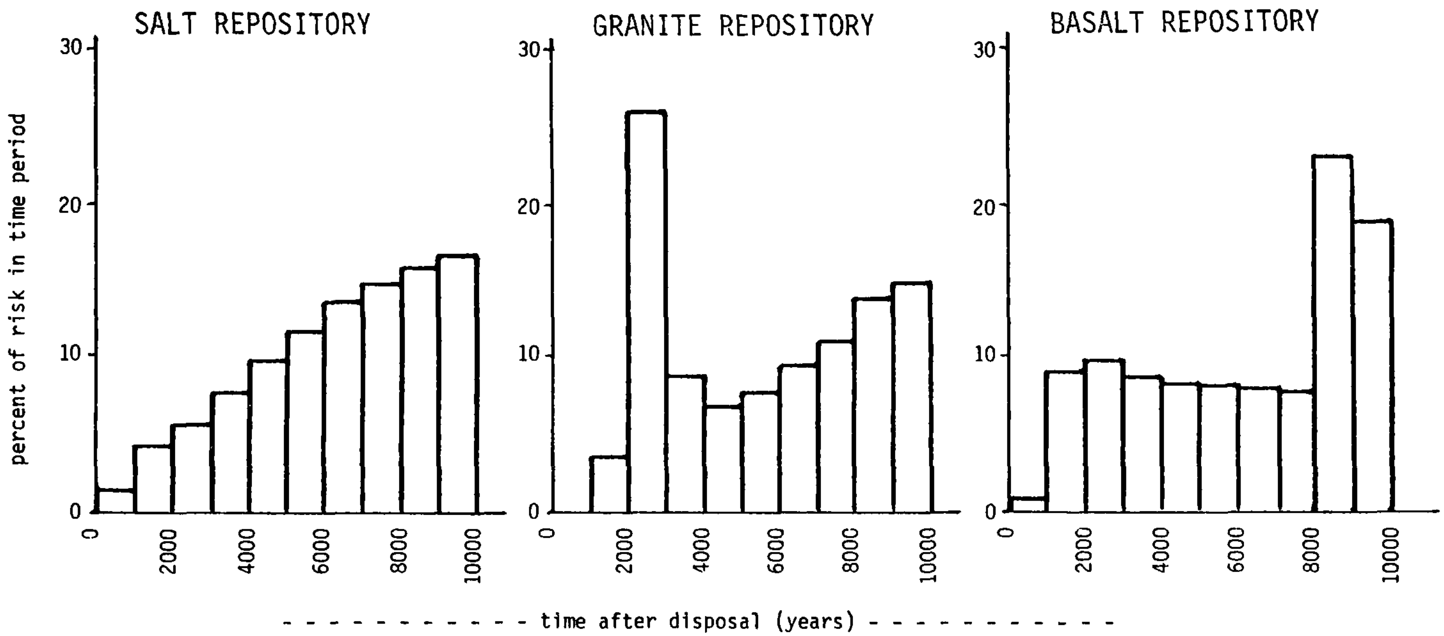
FIGURE 6-2: RELATIVE INCIDENCE OF RESIDUAL RISK FOR A LEVEL OF PROTECTION AT 1,000 HEALTH EFFECTS OVER 10,000 YEARS



We then changed each of the three models in different ways to allow the risks to rise to approximately 10,000 health effects over 10,000 years. For the model salt repository, we assumed that the solubilities of all radionuclides in groundwater were unlimited. For the granite repository, we assumed that geochemical retardation in the surrounding rock formations did not occur. For the basalt repository, we assumed poorer quality engineered barriers. Figure 6-3 shows the relative incidence of the <u>increases</u> in the residual risks that occur in going from the results of Figure 6-2 to the larger residual risk level of 10,000 health effects over 10,000 years.

In general, there is no consistent pattern in the way the residual risks increase for the three different models. Relaxing the isolation provided by different aspects of our model repositories results in very different fluctuations in the overall performance of the models. However, one common feature can be noted. In each case, the relative increase in the residual risk over the first 1,000 years is very small. This illustrates a major reason for our choice of 10,000 years--rather than 1,000 years--as the time period for our standards. Some of the site characteristics of the models used for Figure 6-3 are much worse than those that we are sure can be relatively easily achieved. However, comparing the residual risks over the first 1,000 years would not indicate these deficiencies. Only by extending the analysis to a much longer time do we see the long-term performance ramifications of major differences in site characteristics.

FIGURE 6-3: RELATIVE INCIDENCE OF INCREASE IN RESIDUAL RISK BETWEEN LEVELS OF PROTECTION OF 1,000 AND 10,000 HEALTH EFFECTS



6.3 Engineering Control Costs and the Level of Protection

Using the analyses summarized in section 6-1, we can assess the types of engineered barriers needed to meet different levels of protection (in each case we assume that the site characteristics offer as much protection as those associated with our generic model). Table 6-1 shows these correlations for salt, granite and basalt. The different categories of waste form and canister are those discussed in Chapter 5.

The information in Table 6-1 can, in turn, be combined with the other cost data in Chapter 5 to assign a range of waste management costs to each level of protection for each of the three media. For example: for basalt at 1,000 health effects, the costs include the costs of a "very good" waste form and a "good" canister; for granite at 1,000 health effects, the costs include a "good" waste form and a "minimum" canister. Practical requirements of handling and transportation will always require canisters and waste forms with some durability. Thus, whenever our performance assessments indicates that no engineering controls would be needed, the corresponding costs always include a "minimum" waste form and canister. Whereever only one or the other type of engineered barrier is needed, the cheaper is selected.

Figures 6-4, 6-5, and 6-6 depict the variation in waste management cost with different levels of protection, assuming that the variation is due only to using different combination of engineered barriers. For these figures, research and development costs are assumed to remain constant at

Table 6-1

Engineering Controls Associated with Different Levels of Protection

	Level of Health Effects (over 10,000 years)			
	100	1,000	5,000	10,000
SALT	Very good waste form or very good canister needed	no engineering controls needed *	no engineering controls needed *	no engineering controls needed *
GRANITE	very good waste form needed	good waste form needed	no engineering controls needed *	no engineering controls needed *
BASALT	very good waste form and very good canister needed	very good waste form and good canister needed	good waste form or good canister needed	fair waste form needed

* = full "cost savings" would not be achievable due to criteria recommending "multiple barriers" and "ALARA" and due to other practical requirements of waste transportation and handling.

Figure 6-4: Variations in Waste Management Cost vs. Level of Protection

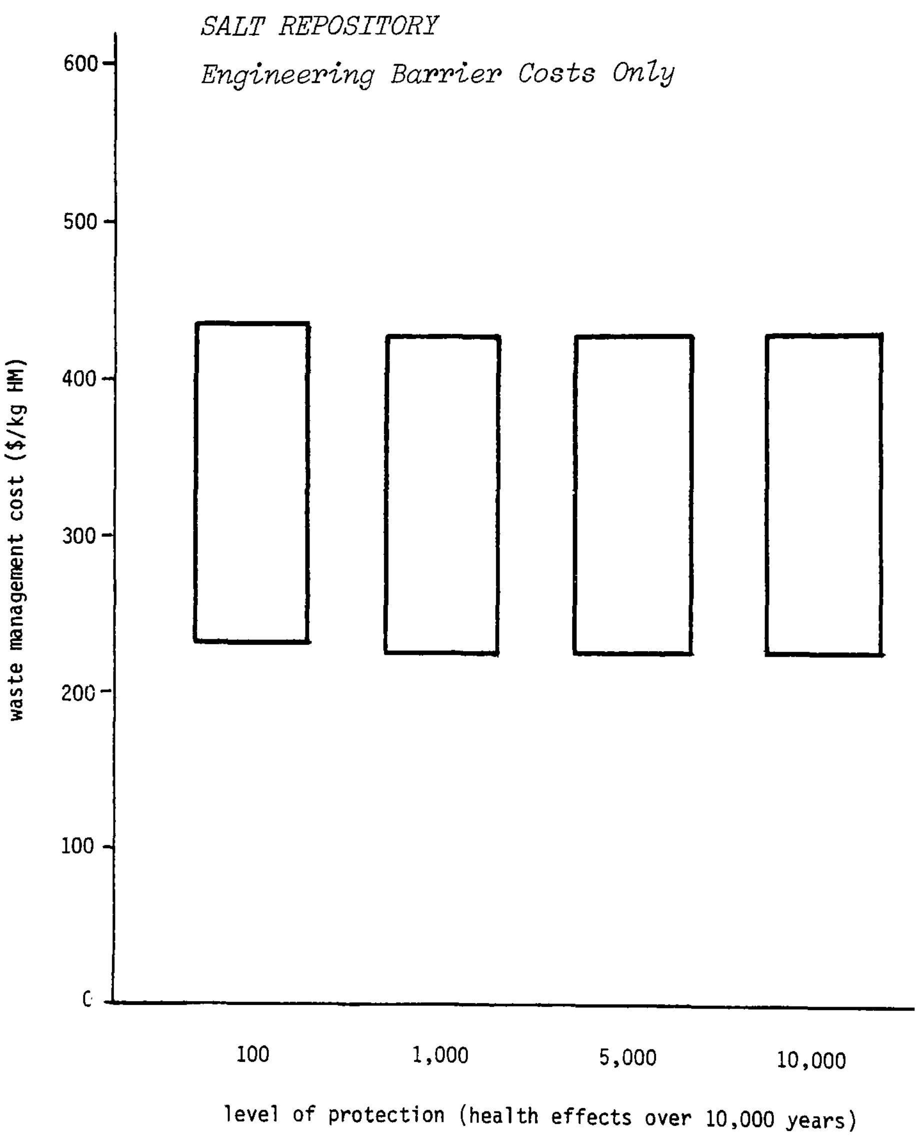


Figure 6-5: Variations in Waste Management Cost vs. Level of Protection

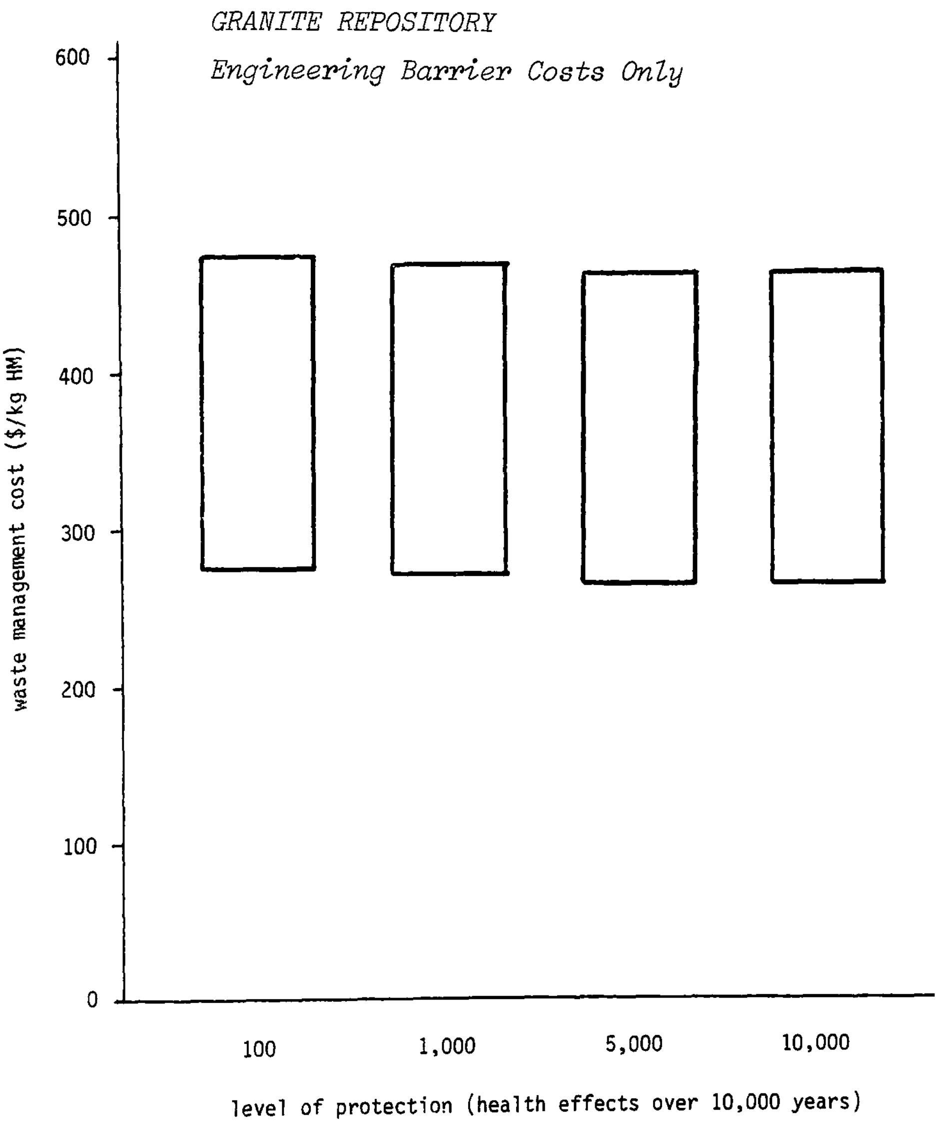
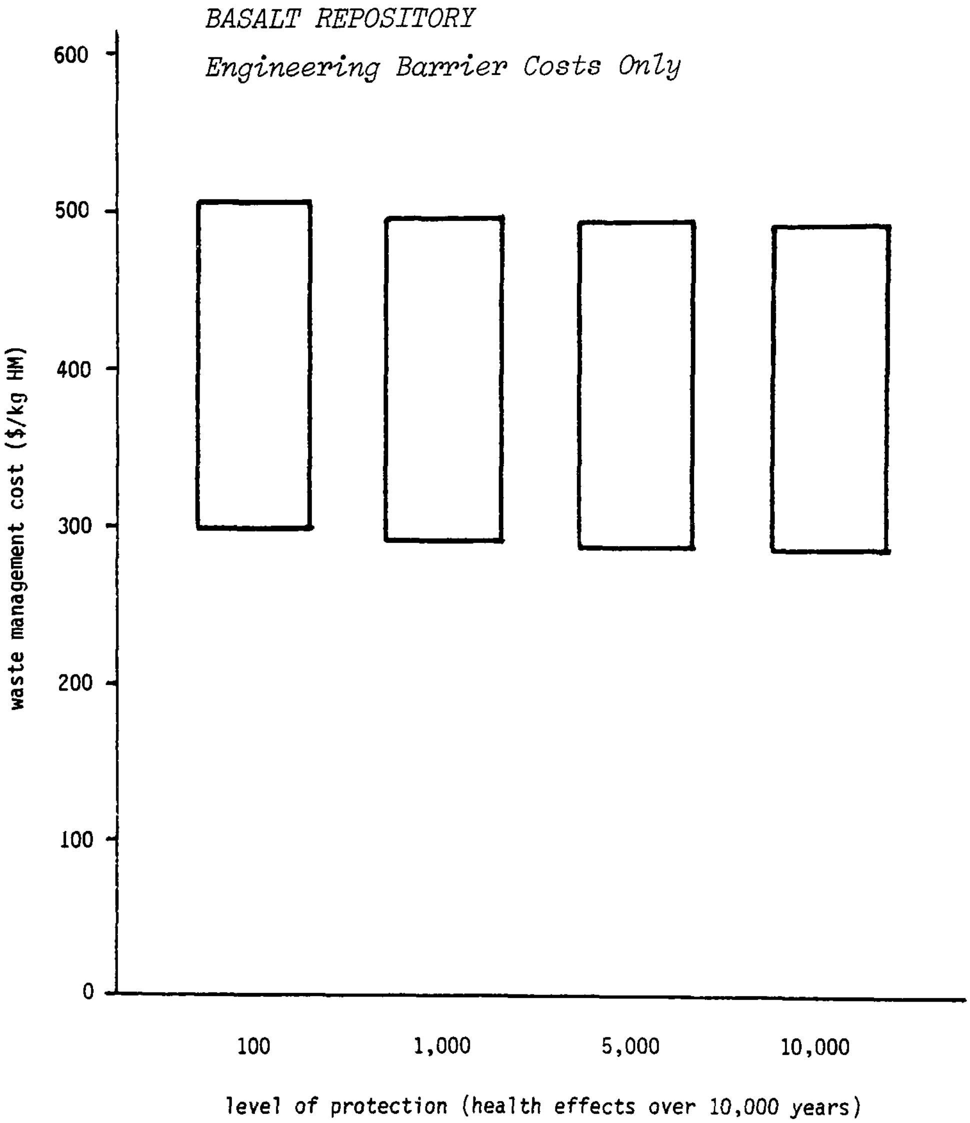


Figure 6-6: Variations in Waste Management Cost vs. Level of Protection



$11-20/kg HM. These results indicate that waste management and disposal costs are not very sensitive to different levels of protection, particularly for the geologic media (bedded salt and granite) that are better at reducing long-term risks. The variations in cost for different levels of protection are considerably less than the overall uncertainties in management and disposal costs. The next section considers possible cost variations caused by the effects of different levels of protection on site selection.

6.4 Site Selection and the Level of Protection

As we explained earlier, the geological and hydrological characteristics of the disposal site provide the most important part of the protection afforded by a repository system. Besides affecting the types of engineering controls used, changing the level of protection could determine how difficult it will be to find adequate sites.

The "cost" of good site characteristics can be considered to be the "site selection" costs needed to identify and evaluate enough sites in order to find one (or more) that is adequate. The procedures called for by NRC's proposed 10 CFR 60 require DOE to investigate at least four sites in detail before selecting one for the first repository. If our standards were stringent enough to prevent any of these first sites from being able to comply, then the national program could be significantly delayed and site selection costs would probably increase substantially. However, we believe that our generic models of repository performance include site characteristics that can be achieved (or improved upon) by reasonably careful site selection.

Until much more information is available about potential sites, the costs of site selection cannot be linked to different levels of our standards. However, to provide some feeling for the possible effect of different site selection costs, we postulated a set of research and development costs (which include site selection) that increase with more stringent levels of protection. These costs were discussed in Chapter 5. We believe these estimates are probably upper bounds on the potential effects of our standard on site selection costs.

Figures 6-7, 6-8, and 6-9 show the effect of considering our postulated variations in site selection cost as well as the potential changes in the costs of engineered barriers. At each level of protection, the corresponding research and development cost was used in deriving the range of total costs described in Chapter 5. As above, the smallest increase with increased stringency is shown for salt, followed by granite and basalt, respectively. In all cases, even with our hypothesis that site selection costs increase with more stringent levels, the variation with different levels of protection is considerably smaller than the overall uncertainty in waste management costs.

Figure 6-7: Variations in Waste Management Cost vs. Level of Protection

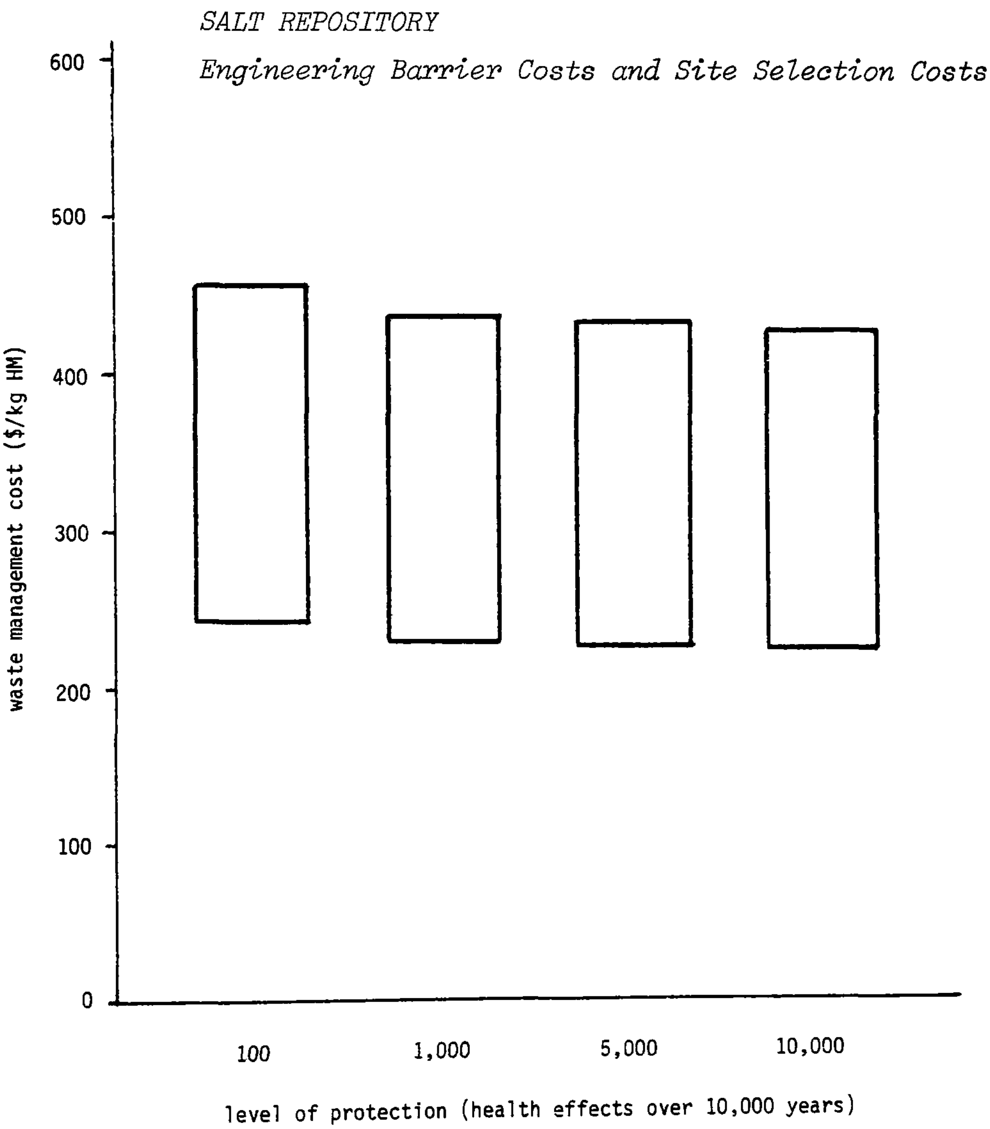


Figure 6-8: Variations in Waste Management Cost vs. Level of Protection

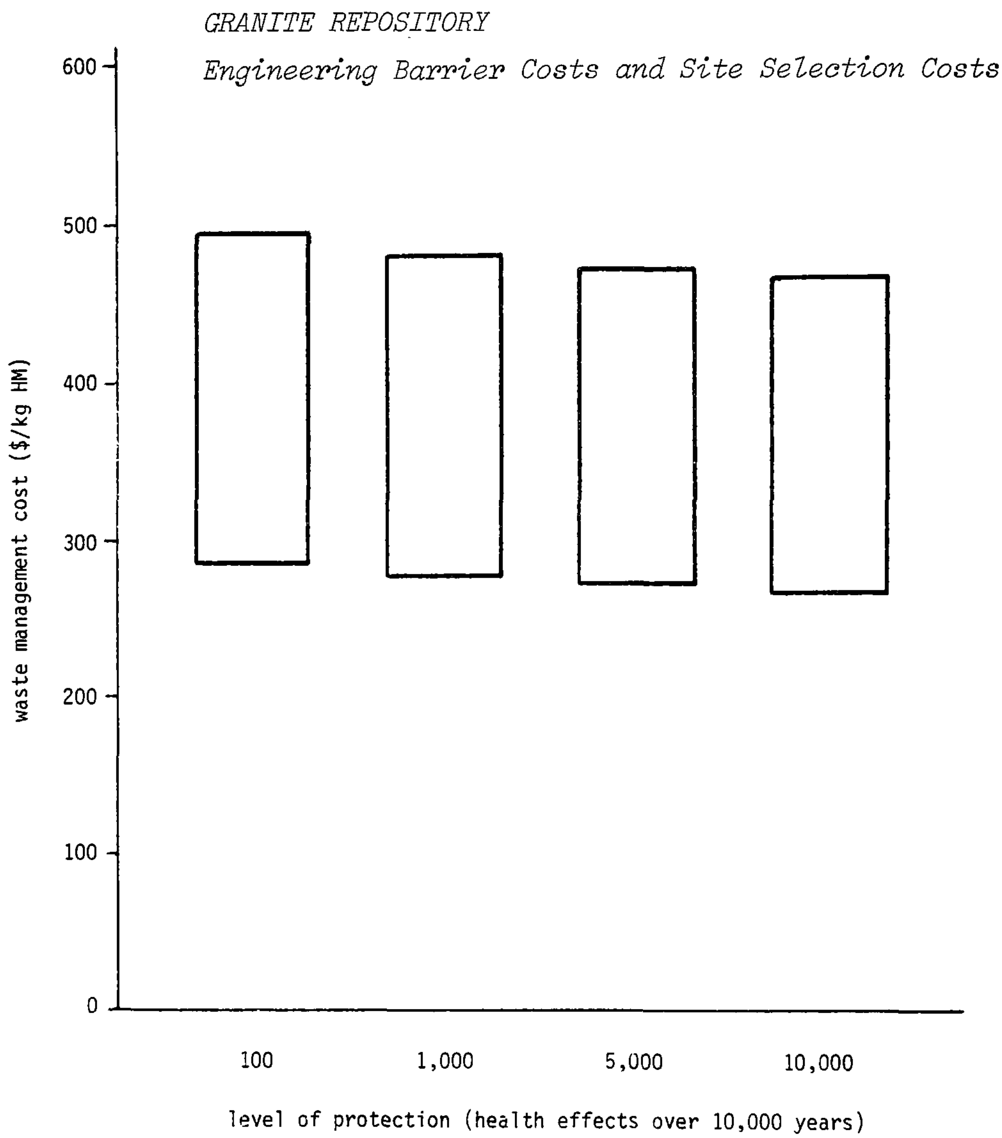
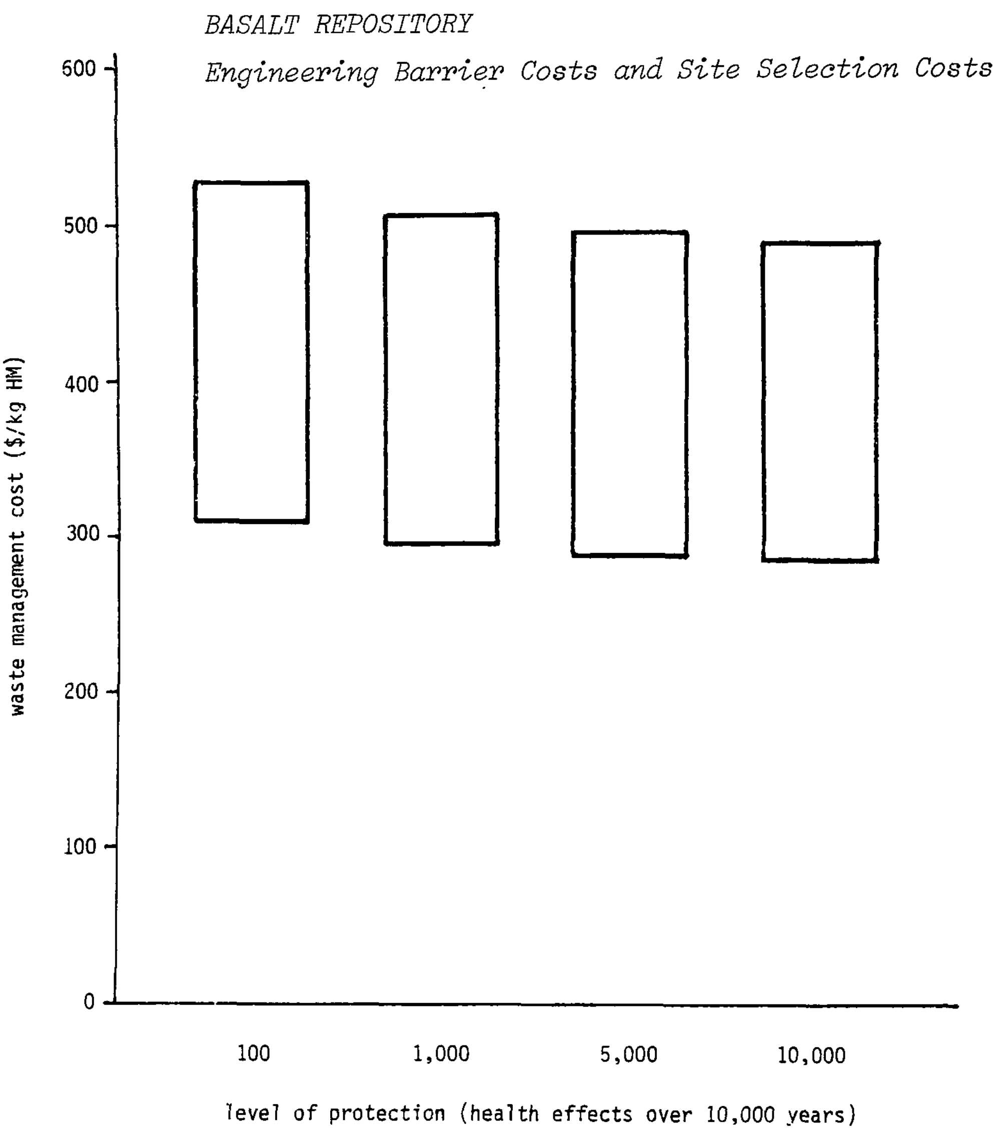


Figure 6-9: Variations in Waste Management Cost vs. Level of Protection



6.5 Economic Impacts of Different Levels of Protection

To estimate the potential economic impacts of the different costs which may be caused by different levels of protection, we first evaluated the impact of a one dollar increase in the cost per kilogram of heavy metal ($/kg HM). In its GEIS (DOE 80), DOE developed a relationship between the cost of waste management and disposal (in $/kg HM) and the increased cost of electricity generated by nuclear reactors (in mils per kilowatt-hour); this conversion factor is one mil/kwh per $233/kg HM. This is slightly larger than the conversion factor DOE used in formulating President Carter's spent fuel policy, which was one mil/kwh per $250/kg HM (DOE 78). Our earlier analysis (LE 80), in turn, developed estimates of the annual increase in costs to electricity consumers caused by various increases in waste management changes. There we estimated that a charge of one mil/kwh would increase costs to consumers in the year 1990 by $825 million/year, assuming that nuclear power would provide 22% of the nation's electricity with an installed nuclear capacity of about 150 GWe. Similar estimates, based on the years 1980 through 1995, indicate that the average annual increase for a one mil/kwh charge would be $700 million/year. Combining these figures, we see that an increase of $1/kg HM in management and disposal costs would correspond to an average annual cost increase to the nation's electricity consumers of about $3 million/year for the years 1980 through 1995.

To provide some perspective on these costs, total electrical utility revenues for 1980 were about $100 billion (DOE 81). Thus, an increase in waste management and disposal costs of $1/kg HM would represent about a

0.003% increase in average electricity rates. With respect to the costs of nuclear power, estimated by DOE to be about 35-50 mils/kwh (1981 dollars) for new plants (DOE 80), an increase of $1/kg HM would represent about a 0.01% increase in the cost of nuclear power. These various "conversion factors" to relate increases in waste management and disposal costs to economic impacts are summarized in Table 6-2.

With these conversion factors, we can now look at the economic impacts of choosing different levels of protection. We will focus on the changes in costs between the level of protection we chose (risks less than 1000 health effects over 10,000 years) and a level of protection ten times less stringent. The reader may wish to use the conversion factors in Table 6-2 to look at other increments.

If we consider only changes in the costs of engineered barriers, the differences in cost between meeting the proposed containment requirements and meeting requirements that allow a residual risk ten times greater are zero for salt, $4/kg HM for granite, and $7/kg HM for basalt. If we then add our hypothethical increases in site selection costs, these cost differences become $6-10/kg HM for salt, $10-14/kg HM for granite, and $13-17/kg HM for basalt. The total range in these differences, with and without the possible increases in site selection costs, is zero to $17/kg HM. This range corresponds to about zero to $50 million/year (1981 dollars) in increased costs to electricity consumers, a zero to 0.05 percent increase in average electricity rates, and a zero to 0.2 percent increase in the costs of nuclear power.

Table 6-2

Relationship of Economic Impacts (1981 dollars) to

Increases in Waste Management and Disposal Costs ($ kg/HM)

Average annual cost increase to electricity consumers for the years 1980 through 1995	$ 3 million/year per $ 1/kg HM
Increase in average electricity rates	0.003 percent per $ 1/kg HM
Increase in nuclear power costs	0.01 percent per $ 1/kg HM

Within these ranges, we think the most likely impacts will be below $10/kg HM, because we think a site as unattractive as our generic model of basalt would probably not be chosen, and because we think our assumptions about site selection costs are probably quite conservative. Thus, the more likely economic impacts between the 1,000 and 10,000 health effect levels are: less than $30 million/year (1981 dollars) in increased consumer costs, less than a 0.03 percent increase in average electricity rates, and less than a 0.1 percent increase in the costs of nuclear power.

6.6 Basis for Selecting the Level of Protection

The issues involved in selecting the level of protection for our proposed environmental standards are different--either in kind or in degree--from those associated with other decisions the Agency typically makes. These differences are caused primarily by two factors:

(1) Absence of established technologies and disposal sites. The various options for disposal of high-level waste are still in the development phase. No facility is now in place, nor is there any specific repository design or site identified as a preferred approach for disposal. Consequently, projections of both cost and performance must be based on generic site and design models. There are substantial uncertainties in these projections, and we cannot know how well they might reflect actual disposal systems until specific sites and designs are selected several years from now.

(2) Long time period of interest. The uncertainties associated with the performance of disposal systems are exacerbated by the long-time period over which these wastes will remain dangerous. Our containment requirements consist of projected radionuclide release limits for 10,000 years after disposal. Therefore, our evaluations of the residual risks associated with these release limits are highly speculative. Food chains, ways of life, and the size and geographical distributions of populations will undoubtedly change substantially over any 10,000 year period. Unlike geological processes, factors such as these cannot be accurately predicted over long periods of time.

Thus, in making our residual risk projections, we used general models of environmental transport of radionuclides and assumed population distributions and death rates very similar to today's (SMJ 82).
The results of these calculations should not be taken as a reliable projection of the "actual" or absolute number of health effects associated with our containment requirements. Rather, the residual risk projections should primarily be used as tools for comparing the performance of one waste disposal system with another, or with the long-term risks from other sources of radionuclides--such as uranium ore bodies.

These inherent limitations, caused by the uncertainties of our estimates, place significant limitations on the kinds of quantitative conclusions which can be drawn from our analyses. For example, without reliable absolute projections of health effects, there is no valid basis upon which a cost per life saved can reasonably be established, nor can the long-term residual risks from these standards be directly compared to the near-term risks estimated for other regulatory actions.

In the absence of the ability to directly make cost-benefit comparions of alternative stringency levels, we considered other tests--measures of economic feasibility and risk acceptability--in order to select a proposed level of protection. Our assessments of economic feasibility are summarized in section 6.4. Even considering the potential effects of site selection costs, the differences in costs for different levels of protection are much smaller than the overall uncertainties in waste management costs and would cause very small economic impacts. For example, the potential impacts caused from selecting the proposed level of protection, rather than one ten times less stringent, are estimated to be: (1) less than a five percent increase in waste management and disposal costs, (2) less than a 0.2 percent increase in the costs of nuclear power, and (3) less than a 0.06 percent increase in average electricty rates.

Even if we were able to make quantitative tradeoffs in terms of the cost per health effect prevented, the applicability of these calculations would be limited by the sharp division in time between the incidence of the benefits derived from the activities which generated these wastes and the incidence of the major risks from disposal of the wastes. For example, the direct benefits associated with nuclear power generated over the past 25 years are tied to a few percent of the total electrical power consumed.

Had the nuclear option not been available, other sources of power could have been substituted fairly easily. The amount of nonrenewable fossil fuels lost to future generations would have been, in relative terms, very small. Consequently, the benefits associated with the generation of these wastes are primarily limited to the current generation.

However, once disposed of in accordance with our proposed standards, the risks associated with these wastes will be practically non-existent for the current generation and the next few generations. Our models indicate that the major incidence of residual risk will not occur until more than 1,000 years after disposal. As a result, a question of intergenerational equity exists with respect to those who bear the risks and those who receive the benefits, and this is a question which cannot be addressed by directly comparing the costs of disposal with the number of health effects prevented.

The issue of intergenerational equity is not unique to high-level radioactive wastes; however, in this situation a unique avenue for addressing the question is available. All high-level wastes have their origin in naturally occuring radioactive materials mined from the Earth's crust. These materials, principally uranium and its decay products, are subject to many of the geochemical and geophysical factors that will affect high-level wastes in a geologic repository--and they can cause health effects through the same environmental pathways that we examined for high-level wastes. Because of the long half-life of uranium, these risks will persist for time periods well beyond the 10,000-year period we considered. Therefore, to provide perspective to the residual risks associated with our proposed standards, we modeled the comparable risks from unmined uranium ore bodies.

Using a quantity of uranium ore equivalent to that needed to generate the quantity of high-level waste contained in our model repositories, we projected a range of health effects for unmined ore bodies that extended from 300 to more than one million health effects over 10,000 years. The lower end of this range is roughly equal to the residual risks associated with our proposed radionuclide release limits. This means that the wastes disposed of in compliance with our containment requirements would pose a risk very close to the minimal risk posed by nature, had these wastes never been generated.

In summary, we believe that the level of protection provided by our proposed standards meets both of our tests: those of economic feasibilty and risk acceptability, even considering the question of intergenerational equity. However, the judgements with respect to the appropiateness of these standards are ultimately societal decisions on the degree of responsibility that the current generation chooses to take with respect to the protection of future generations. The extensive technical analyses supporting these standards primarily serve to clarify the tradeoffs associated with these social decisions. Because of the speculative nature of both the issues and the technical analyses, public review and comment is essential to evaluating the resonableness and appropriateness of our proposed action.

Chapter 7

EFFECTS OF ASSURANCE REQUIREMENTS

In addition to our containment requirements--which focus on providing an overall level of protection--we are also proposing seven qualitative assurance requirements. We believe these qualitative criteria are essential for developing the needed confidence that our long-term containment requirements will be met. The assurance requirements address and compensate for the uncertainties that necessarily accompany plans to isolate high-level wastes from the environment for a very long time. They provide the context necessary for application of our containment requirements, and they should ensure very good long-term protection of the environment. This Chapter evaluates the potential effects of each of these assurance requirements on the costs of waste management and disposal.

> Criterion 1: Wastes shall be disposed of promptly once disposal systems are available and the wastes have been suitably conditioned for disposal.

This criterion is intended to avoid the possibility that these wastes will be stored indefinitely once disposal systems are available, because we do not believe that long-term reliance on active institutional controls is the best way to protect public health and the environment. However, storage that is a planned part of a disposal technique, such as letting high-level waste cool in surface facilities for ten years or more before disposal, would not violate the intent of this assurance requirement.

The effect of this criterion should be to reduce costs, since it should tend to reduce the expenditures for waste storage--which Chapter 5 indicates is one of the more expensive components of waste management and disposal costs.

> Criterion 2: Disposal systems shall be selected and designed to keep releases to the accessible environment as small as reasonably achievable, taking into account technical, social, and economic considerations.

This criterion provides for designing a disposal system to perform better than required by our proposed containment requirements if it appears reasonable to achieve such improved performance. This will help guard against possible mistakes in designing or siting a disposal system. As discussed in Chapter 6, some of our model geologic repository sites would not require any engineered controls to meet our proposed standards. In such situations, this assurance requirement would direct that reasonably capable engineering controls be used anyway. Since waste forms and canisters of significant integrity will be needed for other phases of waste management (particularly for waste transportation to the disposal site), we estimate that any increased costs caused by this criterion would be no more than $2-4/kg HM.

> <u>Criterion 3</u>: Disposal systems shall use several different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included. Each such barrier shall separately be designed to provide substantial isolation.

This criterion should also guard against possible mistakes in designing or siting a disposal system by directing use of a combination of different types of barriers to isolate these wastes. The way in which this assurance requirement might lead to increased disposal costs is essentially the same as for Criterion 3, and our estimate of the potential magnitude of the increase is the same: $2-4/kg HM. It should be noted that this is <u>not</u> an increase <u>in addition</u> to that associated with Criterion 3. Rather, either assurance requirement, or both of them together, would have the same impact.

> <u>Criterion 4</u>: Disposal systems shall not rely upon active institutional controls to isolate the wastes beyond a reasonable period of time (e.g., a few hundred years) after disposal of the wastes.

Limiting long-term reliance on active institutional controls to isolate these wastes may have three different kinds of effects on waste management and disposal costs. First, as discussed for Criterion 1, this assurance requirement could tend to reduce expenditures for waste storage systems and thus reduce the costs of the most expensive phase of waste management. Second, designing for the possibility of human intrusion places increased emphasis on the integrity of a disposal system's engineered barriers, since intrusion can circumvent the protection provided by the natural characteristics of a repository site.

Through the same logic we used for Criteria 2 and 3, we estimate that the magnitude of this potential cost increase would be no more than $2-4/kg HM. Again, thus increase would not be in addition to those for the previous assurance requirements, but would be duplicative. Finally, this assurance requirement could rule out certain relatively unusual sites that would provide adequate protection only if inadvertant intrusion was not possible. (A hypothetical example would be a site in bedded salt that is stable unless drilling inadvertantly creates groundwater flow patterns that cause rapid dissolution of the salt strata--a situation that has occasionally been observed.) However, such situations appear to be sufficiently unusual that site selection procedures based on this assurance requirement could easily avoid any delay or extra cost for the national program.

> Criterion 5: Disposal systems shall be identified by the most permanent markers and records practicable to indicate the dangers of the wastes and their location.

The costs for permanent markers at disposal sites and comprehensive public records--to document the nature of the disposal system and its contents--would appear to be trivial compared to the costs of the disposal systems themselves. Thus, we do not attribute any economic impacts to this assurance requirement.

Criterion 6: Disposal systems shall not be located where there has been mining for resources or where there is a reasonable expectation of exploration for scarce or easily accessible resources in the future. Furthermore, disposal systems shall not be located where there is a significant concentration of any material which is not widely available from other sources.

This assurance requirement could rule out an otherwise acceptable site because of the relative liklihood of human intrusion. For example, the frequent mining of salt domes either for their relatively pure salt or for use as storage caverns would argue against locating a repository in this type of structure. (This concern would generally not apply to bedded salt deposits because they are much more common--but the criterion could rule out specific bedded salt sites if they were associated with significant occurrences of other resources.) This assurance requirement is more likely to rule out an site than Criterion 4 would be. However, we still believe that site selection procedures based on Criterion 6 could avoid any delay or extra cost for the national program.

Criterion 7: Disposal systems shall be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal.

Mined geologic repositories, with their wastes contained in capable engineered barriers, meet this assurance requirement by their inherent characteristics. Since the national program is now focused on this type of disposal system, we do not foresse any cost effects due to this requirement.

Appendix

THE PROPOSED STANDARDS

A new Part 191 is proposed to be added to Title 40, Code of Federal Regulations, as follows:

SUBCHAPTER F - RADIATION PROTECTION PROGRAMS

PART 191 - ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR MANAGEMENT AND DISPOSAL OF SPENT NUCLEAR FUEL, HIGH-LEVEL AND TRANSURANIC RADIOACTIVE WASTES

Subpart A - Environmental Standards for Management and Storage

Subpart B - Environmental Standards for Disposal

AUTHORITY: The Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970.

SUBPART A - ENVIRONMENTAL STANDARDS FOR MANAGEMENT AND STORAGE

191.01 Applicability

This Subpart applies to radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel, high-level, or transuranic radioactive wastes, to the extent that these operations are not subject to the provisions of Part 190 of Title 40.

191.02 Definitions

Unless otherwise indicated in this Subpart, all terms shall have the same meaning as in Subpart A of Part 190.

(a) "Spent nuclear fuel" means any nuclear fuel removed from a nuclear reactor after it has been irradiated.

(b) "High-level radioactive wastes" means any of the following that contain radionuclides in concentrations greater than those identified in Table 1: (1) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, in a facility for reprocessing spent nuclear fuels; (2) the concentrated wastes from subsequent extraction cycles, or equivalent; (3) solids into which such liquid wastes have been converted; or (4) spent nuclear fuel if disposed of without reprocessing.

(c) "Transuranic wastes," as used in this Part, means wastes containing more than 100 nanocuries of alpha emitting transuranic isotopes, with half-lives greater than one year, per gram of waste.

(d) "Storage" means placement of radioactive wastes with planned capability to readily retrieve such materials.

(e) "Management and storage" means any activity, operation, or process, except for transportation, conducted to prepare spent nuclear fuel, high-level or transuranic radioactive wastes for storage or disposal, the storage of any of these materials, or activities associated with the disposal of these materials.

(f) "General environment" means the total terrestial, atmospheric, and aquatic environments outside sites within which any operation associated with the management and storage of spent nuclear fuel, high-level or transuranic radioactive wastes is conducted.

(g) "Member of the public" means any individual who is not engaged in operations involving the management, storage, and disposal of materials covered by these standards. A worker so engaged is a member of the public except when on duty at a site.

191.03 Standards for Normal Operations

Operations covered by this Subpart should be conducted so as to reduce exposures to members of the public to the extent reasonably achievable, taking into account technical, social, and economic considerations. As an upper limit, except for variances in accordance with 191.04, these operations shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public due to: (a) operations covered by Part 190,

(b) planned discharges of radioactive material to the general environment from operations covered by this Subpart, and (c) direct radiation from these operations; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, or 25 millirems to any other organ.

191.04 Variances for Unusual Operations

(a) The implementing agency may grant a variance temporarily authorizing operations which exceed the standards specified in 191.03 when abnormal operating conditions exist if: (1) a written request justifiying continued operation has been submitted, (2) the costs and benefits of continued operation have been considered to the extent possible, (3) the alternatives to continued operation have been considered, and (4) continued operation is deemed to be in the public interest.

(b) Before the variance is granted, the implementing agency shall announce, by publication in the Federal Register and by letter to the governors of affected States: (1) the nature of the abnormal operating conditions, (2) the degree to which continued operation is expected to result in doses exceeding the standards, (3) the proposed schedule for achieving conformance with the standards, and (4) the action planned by the implementing agency.

191.05 Effective Date

The standards in this Subpart shall be effective 12 months from the promulgation date of this rule.

SUBPART B - ENVIRONMENTAL STANDARDS FOR DISPOSAL

191.11 Applicability

This Subpart applies to radioactive materials released into the accessible environment as a result of the disposal of high-level or transuranic radioactive wastes, including the disposal of spent nuclear fuel. This Subpart does not apply to disposal directly into the oceans or ocean sediments.

191.12 Definitions

Unless otherwise indicated in this Subpart, all terms shall have the same meaning as in Subpart A of this Part.

(a) "Disposal" means isolation of radioactive wastes with no intent to recover them.

(b) "Barriers" means any materials or structures that prevent or substantially delay movement of the radioactive wastes toward the accessible environment.

(c) "Disposal system" means any combination of engineered and natural barriers that contains radioactive wastes after disposal.

(d) "Groundwater" means water below the land surface in a zone of saturation.

(e) "Lithosphere" means the solid part of the Earth, including any groundwater contained within it.

(f) "Accessible environment" includes (1) the atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) parts of the lithosphere that are more than ten kilometers in any direction from the original location of any of the radioactive wastes in a disposal system.

(g) "Reasonably foreseeable releases" means releases of radioactive wastes to the accessible environment that are estimated to have more than one chance in 100 of occurring within 10,000 years.

(h) "Very unlikely releases" means releases of radioactive wastes to the accessible environment that are estimated to have between one chance in 100 and one chance in 10,000 of occurring within 10,000 years.

(i) "Performance assessment" means an analysis which identifies those events and processes which might affect the disposal system, examines their effects upon its barriers, and estimates the probabilities and consequences of the events. The analysis need not evaluate risks from all identified events. However, it should provide a reasonable expectation that the risks from events not evaluated are small in comparison to the risks which are estimated in the analysis.

(j) "Active institutional controls" means (1) guarding a disposal site, (2) performing maintenance operations or remedial actions at a disposal site, or (3) controlling or cleaning up releases from a disposal site.

(k) "Passive institutional controls" means (1) permanent markers placed at a disposal site, (2) public records or archives, (3) Federal Government ownership or control of land use, or (4) other methods of preserving knowledge about the location, design, or contents of a disposal system.

(l) "Heavy metal" means all uranium, plutonium, or thorium placed into a nuclear reactor.

191.13 Containment Requirements

Disposal systems for high-level or transuranic wastes shall be designed to provide a reasonable expectation that for 10,000 years after disposal:

(a) Reasonably foreseeable releases of waste to the accessible environment are projected to be less than the quantities calculated according to Table 2.

(b) Very unlikely releases of waste to the accessible environment are projected to be less than ten times the quantities calculated according to Table 2.

191.14 Assurance Requirements

To provide the confidence needed for compliance with the containment requirements of 191.13, disposal of high-level or transuranic wastes shall be conducted in accordance with the following requirements:

(a) Wastes shall be disposed of promptly once disposal systems are available and the wastes have been suitably conditioned for disposal.

(b) Disposal systems shall be selected and designed to keep releases to the accessible environment as small as reasonably achievable, taking into account technical, social, and economic considerations.

(c) Disposal systems shall use several different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included. Each such barrier shall separately be designed to provide substantial isolation.

(d) Disposal systems shall not rely upon active institutional controls to isolate the wastes beyond a reasonable period of time (e.g., a few hundred years) after disposal of the wastes.

(e) Disposal systems shall be identified by the most permanent markers and records practicable to indicate the dangers of the wastes and their location.

(f) Disposal systems shall not be located where there has been mining for resources or where there is a reasonable expectation of exploration for scarce or easily accessible resources in the future. Furthermore, disposal systems shall not be located where there is a significant concentration of any material which is not widely available from other sources.

(g) Disposal systems shall be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal.

191.15 Procedural Requirements

Performance assessments to determine compliance with the containment requirements of 191.13 shall be conducted in accordance with the following:

(a) The assessments shall consider realistic projections of the protection provided by all of the engineered and natural barriers of a disposal system.

(b) The assessments shall not assume that active institutional controls can prevent or reduce releases to the accessible environment beyond a reasonable period (e.g., a few hundred years) after disposal. However, it should be assumed that the Federal Government is committed to retaining passive institutional control of disposal sites in perpetuity. Such passive controls should be effective in deterring systematic or persistent exploitation of a disposal site, and it should be assumed that they can keep the chance of inadvertent human intrusion very small as long as the Federal Government retains such passive control of disposal sites.

(c) The assessments shall use information regarding the likelihood of human intrusion, and all other unplanned events that may cause releases to the accessible environment, as determined by the implementing agency for each particular disposal site.

191.16 Effective Date

The standards in this Subpart shall be effective immediately upon promulgation of this rule; however, this Subpart does not apply to wastes disposed of before promulgation of this rule.

TABLE 1 - CONCENTRATIONS IDENTIFYING HIGH-LEVEL RADIOACTIVE WASTES

Radionuclide	Concentration (curies per gram of waste)
Carbon-14	8×10^{-6}
Cesium-135	8×10^{-4}
Cesium-137	5×10^{-3}
Plutonium-241	3×10^{-6}
Strontium-90	7×10^{-3}
Technetium-99	3×10^{-6}
Tin-126	7×10^{-7}
Any alpha-emitting transuranic radionuclide with a half-life greater than 20 years	1×10^{-7}
Any other radionuclide with a half-life greater than 20 years	1×10^{-3}

NOTE: In cases where a waste contains a mixture of radionuclides, it shall be considered a high-level radioactive waste if the sum of the ratios of the radionuclide concentration in the waste to the concentration in Table 1 exceeds one.

For example, if a waste containing radionuclides A, B, and C in concentrations C_a, C_b, and C_c, and if the concentration limits from Table 1 are CL_a, CL_b, and CL_c, then the waste shall be considered high-level radioactive waste if the following relationship exists:

$$\frac{C_a}{CL_a} + \frac{C_b}{CL_b} + \frac{C_c}{CL_c} \geq 1$$

TABLE 2 - RELEASE LIMITS FOR CONTAINMENT REQUIREMENTS

(Cumulative Releases to the Accessible Environment

for 10,000 Years After Disposal)

Radionuclide	Release Limit (curies per 1000 MTHM)
Americium-241	10
Americium-243	4
Carbon-14	200
Cesium-135	2000
Cesium-137	500
Neptunium-237	20
Plutonium-238	400
Plutonium-239	100
Plutonium-240	100
Plutonium-242	100
Radium-226	3
Strontium-90	80
Technetium-99	10000
Tin-126	80
Any other alpha-emitting radionuclide	10
Any other radionuclide which does not emit alpha particles	500

NOTE 1: The Release Limits in Table 2 apply either to the amount of high-level wastes generated from 1,000 metric tons of heavy metal (MTHM), or to an amount of transuranic (TRU) wastes containing one million curies of alpha-emitting transuranic radionuclides. To develop Release Limits for a particular disposal system, the quantities in Table 2 shall be adjusted for the amount of wastes included in the disposal system. For example:

(a) If a particular disposal system contained the high-level wastes from 50,000 MTHM, the Release Limits for that system would be the quantities in Table 2 multiplied by 50 (50,000 MTHM divided by 1,000 MTHM).

(b) If a particular disposal system contained five million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 2 multiplied by five (five million curies divided by one million curies).

(c) If a particular disposal system contained both the high-level wastes from 50,000 MTHM <u>and</u> 5 million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 2 multiplied by 55:

$$\frac{50{,}000 \text{ MTHM}}{1{,}000 \text{ MTHM}} + \frac{5{,}000{,}000 \text{ curies TRU}}{1{,}000{,}000 \text{ curies TRU}} = 55$$

NOTE 2: In cases where a mixture of radionuclides is projected to be released, the limiting values shall be determined as follows: For each radionuclide in the mixture, determine the ratio between the cumulative release quantity projected over 10,000 years and the limit for that radionuclide as determined from Table 2 and Note 1. The sum of such ratios for all the radionuclides in the mixture may not exceed one.

For example, if radionuclides A, B, and C are projected to be released in amounts Q_a, Q_b, and Q_c, and if the applicable Release Limits are RL_a, RL_b, and RL_c, then the cumulative releases over 10,000 years shall be limited so that the following relationship exists:

$$\frac{Q_a}{RL_a} + \frac{Q_b}{RL_b} + \frac{Q_c}{RL_c} \leq 1$$

REFERENCES

(ADL 79) Arthur D. Little, Inc., 1979. Technical Support of Standards for High-Level Radioactive Waste Management: Volume B: Enginering Controls. U.S. Environmental Protection Agency (EPA/520/4-79-007), Washington, D.C.

(DOE 80) U.S. Department of Energy, October 1980. Final Environmental Impact Statement: Management of Commercially Generated Radioactive Waste. U.S. Department of Energy (DOE/EIS-0046F), Washington, D.C.

(DOE 81) U.S. Department of Energy, 1981. Monthly Energy Review. U.S. Department of Energy (DOE/EIA-0035(81)) Washington, D.C.

(EPA 82) U.S. Environmental Protection Agency, 1982. Draft Environmental Impact Statement for 40 CFR 191: Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. U.S. Environmental Protection Agency (EPA 520/1-82-025), Washington, D.C.

(IRG 79) Interagency Review Group on Nuclear Waste Management, March, 1979. "Report to the President". National Technical Information Service (TID-28817), Springfield, Virginia 22161.

(JA 81) Jardine, L.J., R.E. Carlton, and M.J. Steindler, 1981. Comparison of Costs for Solidification of High-Level Radioactive Waste Solutions: Glass Monoliths vs. Metal Matrices. Argonne National Laboratories (ANL-80-121), Argonne, Illinois.

(LE 80) Leiter, Andrew J., December 1980. Economic Impacts of 40 CFR 191: Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. U.S. Environmental Protection Agency (EPA 520/4-80-014), Washington, D.C.

(NRC 80) U.S. Nuclear Regulatory Commission, 1980. Advance Notice of Proposed Rulemaking, 10 CFR Part 60: "Technical Criteria for Regulating Disposal of High-Level Radioactive Waste," Federal Register, Vol. 45, No. 94, page 31393.

(SA 81) Sandsberry, D., Department of Commerce, Bureau of the Census. Personal conversation with Byron Bunger, U.S. Environmental Protection Agency, September 1981.

(SMC 82) Smith, C.B., D.J. Egan, W.A. Williams, J.M. Gruhlke, C.Y. Hung, and B. Serini, 1982. Population Risks from Disposal of High-Level Radioactive Wastes in Geologic Repositories. U.S. Environmental Protection Agency (EPA 520/3-80-006), Washington, D.C.

(SMJ 82) Smith, J.M., T.W. Fowler and A.S. Goldin, 1982. Environmental Pathway Models for Estimating Population Risks from Disposal of High-Level Radioactive Waste in Geologic Repositories. U.S. Environmental Protection Agency (EPA 520/5-80-002), Washington, D.C.

(VI 81) Vieth, D., Department of Energy. Personal conversation with Daniel Egan, U.S. Environmental Protection Agency, October 1981.

(WA 81) Walton, R., Department of Energy. Personal conversation with Daniel Egan, U.S. Environmental Protection Agency, October 1981.

(WI 80) Williams, W.A., 1980. Population Risks from Uranium Ore Bodies. U.S. Environmental Protection Agency (EPA 520/3-80-009), Washington, D.C.