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Final Regulatory Impact Analysis
40 CFR Part 191
Environmental Standards for the Management and Disposal of Spent Nuclear Fuel High-Level and Transuranic Radioactive Wastes

EPA 520/1-85-027

FINAL
REGULATORY IMPACT ANALYSIS

40 CFR PART 191

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

AUGUST 1985

U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

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Chapter 1

INTRODUCTION AND SUMMARY

This Final Regulatory Impact Analysis (RIA) addresses the requirements of Section 2 of Executive Order No. 12291. It reviews the projected costs associated with management and disposal of the high-level radioactive wastes (or spent nuclear fuel) generated by nuclear power plants. It then evaluates the potential effects on the program for mined geologic repositories, as called for by the Nuclear Waste Policy Act of 1982 (NWPA), of the Agency's final environmental standards for disposal of these wastes. These standards are located in Part 191 of Title 40 of the Code of Federal Regulations (40 CFR 191). This Final RIA is based on the Draft RIA (EPA 82) that was published with the version of these standards proposed for public review and comment on December 29, 1982 (47 FR 58196). The Final RIA reflects changes in the standards made after considering the comments received, and it also takes into account several recommendations made by the subcommittee of the Agency's Science Advisory Board (SAB) that reviewed the technical basis of the proposed rule (SAB 84).

The situation regarding the disposal of high-level wastes is unusual from a regulatory standpoint. In most cases, a regulation addresses an ongoing activity. Any modifications that the regulation causes in the conduct of that activity may be considered to be costs that should be outweighed by the corresponding regulatory benefits. For high-level waste disposal, however, the Executive branch has long assumed--and the Congress has now mandated--that the appropriate environmental 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. There is no ongoing "baseline" program to consider.

Instead, this Final RIA uses the current and planned programs of the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC) to provide a framework for investigating the potential regulatory impacts of these environmental standards. The RIA evaluates how the costs of high-level waste disposal might change: (1) due to alternative stringency levels for the numerical containment requirements of the disposal standards, and (2) due to alternative levels and durations for the individual and ground water protection portions of the disposal standards. This evaluation uses information about potential disposal sites that DOE has already collected through its site evaluation programs, and the evaluation reflects several provisions of the technical criteria that the NRC has already promulgated for geologic disposal of high-level wastes (10 CFR 60).

Like most environmental regulations, the benefits of these standards can be discussed in terms of damages to public health and the environment that are avoided (or allowed) at various levels of stringency. While the analyses described in this RIA associate potential health impacts (in terms of premature fatal cancers and serious genetic effects) with different levels of the disposal standards, assessing the benefits of these standards in such terms may be misleading because of the very long time frames considered.

Calculations of the residual risks allowed by the standards are not reliable as absolute values, since projections of population distributions, life styles, and human behavior over 10,000 years can only be based on conjecture. Instead, these calculations are valuable only for understanding the relative residual risks from different sources of radiation exposure (such as risks from different disposal designs or risks from natural uranium ore bodies).

However, the most important benefit of these standards does not depend upon the absolute validity of these quantitative calculations. Instead, this benefit consists of the general confidence these standards provide that management and disposal of these wastes will be accomplished with exceptional protection of the environment and with residual risks that are clearly very small. This confidence should, in turn, facilitate the national program to evaluate, select, and construct acceptable disposal methods that will reduce the risks and costs of indefinite storage of the materials covered by these standards. 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 advantages, economic and otherwise, compared to alternative methods of generating electricity; however, this RIA does not analyze the comparative benefits of nuclear power.

1.1 Analytical Framework

To investigate the potential effects of the standards on the costs of waste disposal, the Agency assembled analytical models of three of the disposal sites being considered by the Department of Energy: the site in basalt flows on the Hanford reservation in Washington and two sites in bedded salt formations, one in the Palo Duro Basin in Texas and the other in the Paradox formation in Utah. These models evolved from much more generic models that were used for the development of the proposed standards. Although the Agency has not assembled models for all of the nine sites that the Department is now evaluating in accordance with the site selection process established by the NWPA, the three sites considered appear representative of the range of performance that might be expected from any of the sites. The two models for bedded salt sites should represent the performance of any of the seven sites in salt formations, within the accuracy of these analyses. Other analyses reported in the Background Information Document (EPA 85) for this rule indicate that performance of the unsaturated tuff site in Nevada also appears to be similar to that of the bedded salt models.

Furthermore, the Agency considered the effects of the engineered barriers that are to be used in building disposal systems for high-level wastes. The NRC has required that waste packages contain the wastes for 300 to 1,000 years after disposal and that the release rate after that time be no more than one part in 100,000 for important radionuclides (10 CFR 60). These requirements are used as a baseline for the analyses in this RIA, although the effects of alternative assumptions for package lifetimes and waste form release rates are also examined.

1.2 Containment Requirements

The containment requirements in the disposal standards consist of limits on projected releases of radioactivity from a disposal system for 10,000 years after disposal of the wastes. To evaluate the risks associated with these release limits, generalized environmental pathway models were developed to assess the potential health risks of such releases (SM 85). For the containment requirements in the final rule, the residual risks projected by these models would be less than 1,000 deaths from cancer over the 10,000-year period, an average of one premature cancer death every 10 years. This is the same residual risk that was associated with the proposed rule. To judge the effects on disposal costs of changing this level of protection, the Agency also considered containment requirements with residual risk values of 100 and 10,000 premature cancer deaths over the 10,000-year period. This range of residual risks was chosen because it corresponds to the range of performance expected of mined geologic repositories.

Two types of effects were investigated. First, long-term performance assessments were used to evaluate the quality of engineered controls that would be needed in each of the three model repositories to meet each of the three different levels of protection. Assessing the costs of engineered controls of different quality was difficult, however, because development of specific technologies (canisters, waste forms, etc.) has not yet progressed far enough to clearly associate the costs of manufacturing these engineered barriers with their performance levels. Thus, rather tentative judgments had to be made to associate engineered barrier costs with alternative stringency levels.

Second, potential effects of the level of protection on the costs of demonstrating compliance with the standards were considered. Reliable perspectives on such costs cannot be developed until the national program has proceeded to characterize potential sites and the implementing agencies have had an opportunity to consider compliance with the types of data collected at such sites. Accordingly, this RIA can only speculate on the effects of the standards on such costs. To carry out this analysis, it has been assumed that the costs of research and development at a site could be increased by 50 percent when the projected performance of the disposal system is less than an order of magnitude below the residual risks allowed by the standards. Thus, for the risk level of 1,000 cancer deaths over 10,000 years, it is assumed that research and development costs increase when a disposal system (site characteristics plus engineered barriers) projects risk levels above 100 cancer deaths over 10,000 years.

Figures 1-1 and 1-2 display the results of these analyses for the basalt and bedded salt model sites considered. These figures show the results with and without the assumption that the engineered barrier requirements in 10 CFR 60 are met. These analyses demonstrate that the costs of disposal are not very sensitive to different levels of protection. In fact, if it is assumed that the requirements of 10 CFR 60 are met, there are no additional costs for any of the model sites to meet the level of protection called for by the containment requirements--compared with a level of protection ten times less stringent. If the requirements of 10 CFR 60 are

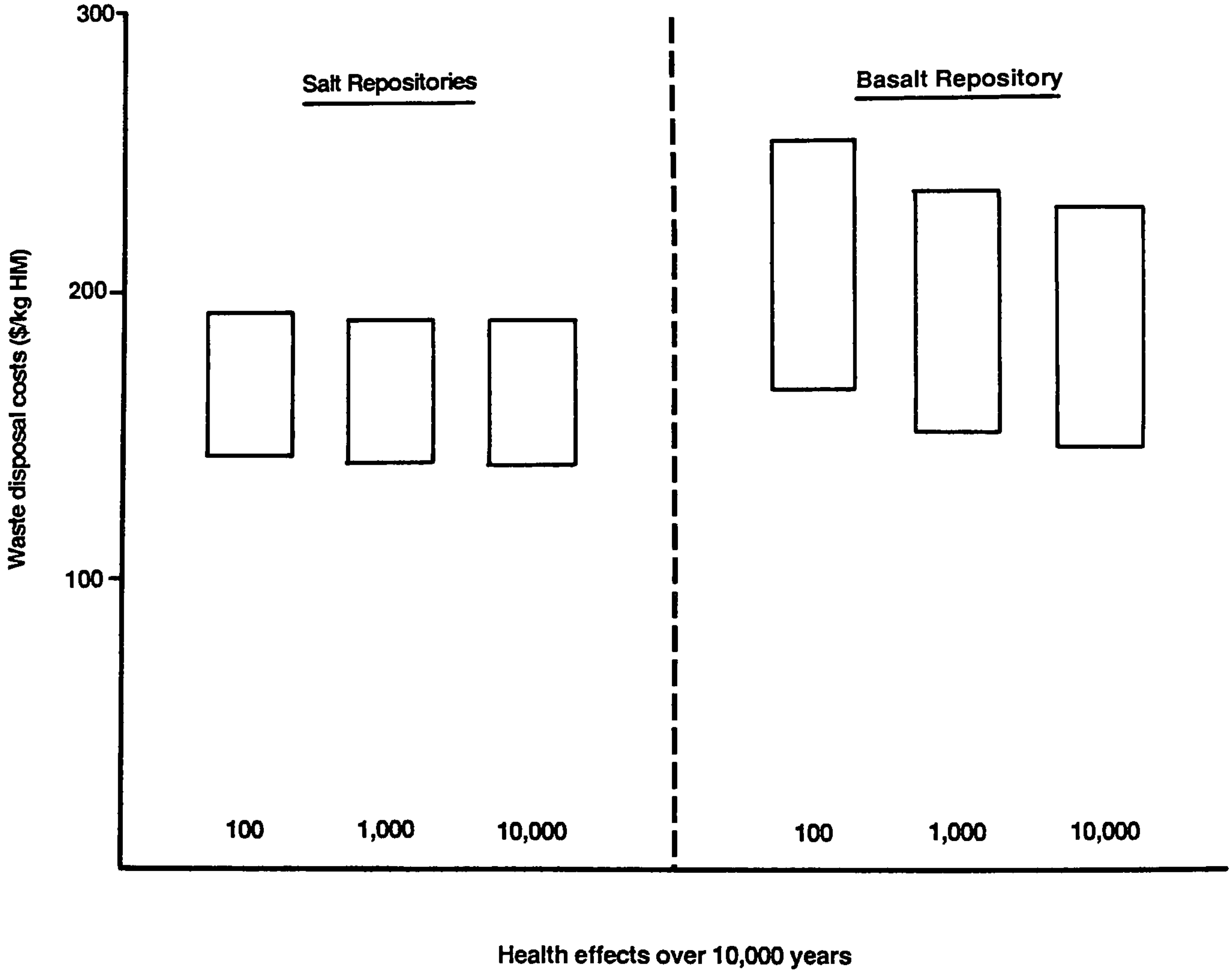


Figure 1-1. Waste disposal costs as a function of various levels of protection assuming non-compliance with 10 CFR 60

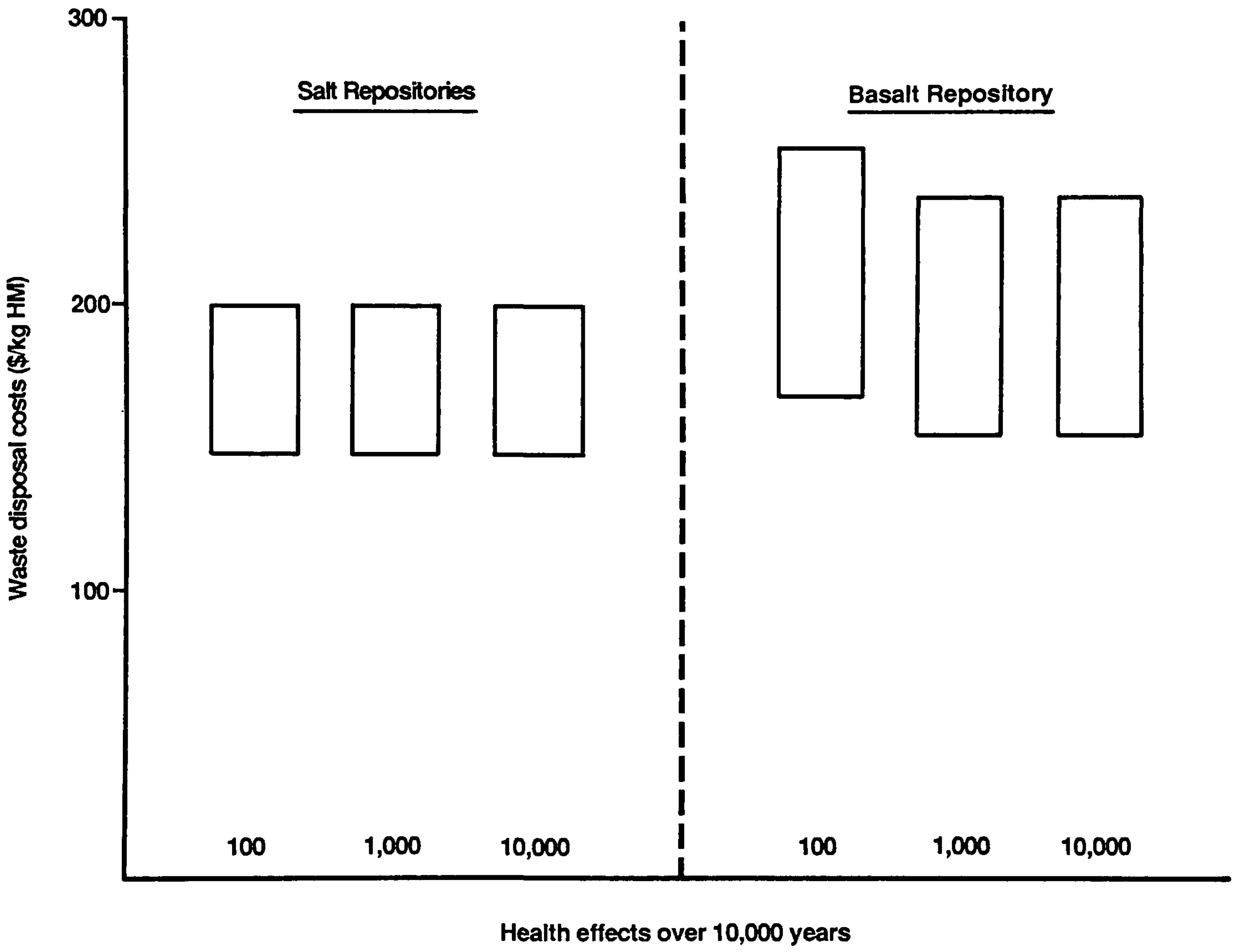


Figure 1-2. Waste disposal costs as a function of various levels of protection assuming compliance with 10 CFR 60

not considered, there still appear to be no additional costs to meet the chosen level of protection at the bedded salt sites. However, additional costs for engineered barriers would be projected for the basalt site at a residual risk level of 1,000 deaths over 10,000 years, compared to a level of 10,000 deaths. These additional costs would be about 6 to 12 million (1984) dollars per year. For comparison, the total costs of high-level waste disposal (independent of this action) are estimated to be between 400 million and 700 million (1984) dollars per year. Electrical utility revenues were about 150 billion dollars in 1984, of which about 20 billion dollars were generated by sales of electricity generated by nuclear power plants (DOE 85).

1.3 Individual and Ground Water Protection Requirements

These sections of the final rule, which were added in response to comments received on the proposed standards, limit both concentrations of radionuclides in certain ground waters and exposures of individuals for 1,000 years after disposal. Unlike the containment requirements, which apply to a wide range of unlikely or unplanned releases, these provisions apply only to undisturbed performance of the disposal system. The three models of geologic repositories used to evaluate the containment requirements were also used to assess the effects of setting these standards at different levels and for different periods of time. As described in Chapter 5, there appear to be virtually no practical effects due to varying the level of protection afforded by these requirements over a reasonable range of protection and considering the expected range of engineered barrier performance. However, there can be significant effects associated with different durations of these requirements. These impacts were investigated by comparing individual and ground water protection requirements established over durations of 100, 1,000, and 10,000 years.

Figures 1-3 and 1-4 illustrate the results of these analyses in terms of potential cost impacts of different durations of the individual and ground water protection requirements. Because engineered barrier performance appears to be the most sensitive variable in determining compliance with these provisions, only the costs of different qualities of waste packages and waste forms were considered. From this perspective, there are significant differences in the performance of the different types of geologic media. Because the natural characteristics of the salt sites appear to prevent any release of radioactivity due to normal ground water flow for tens of thousands of years, there appear to be no cost effects associated with setting these individual and ground water protection requirements at any point within the range of durations considered. However, for the basalt site, there can be major impacts. If compliance with 10 CFR 60 is assumed (particularly with a 1,000-year waste package lifetime), there do not appear to be differences in cost between durations of 100 and 1,000 years. However, if 10 CFR 60 is not considered, then it may cost up to 15 million dollars per year for these provisions to extend for 1,000 years rather than 100 years at the basalt site. Whether or not 10 CFR 60 is considered, the impacts of extending the ground water and individual protection requirements to 10,000 years appear to be quite large at the basalt site. Waste packages that assured containment for almost all of the 10,000-year period would be needed, and these are estimated to add almost 100 million dollars per year to the cost of disposal.

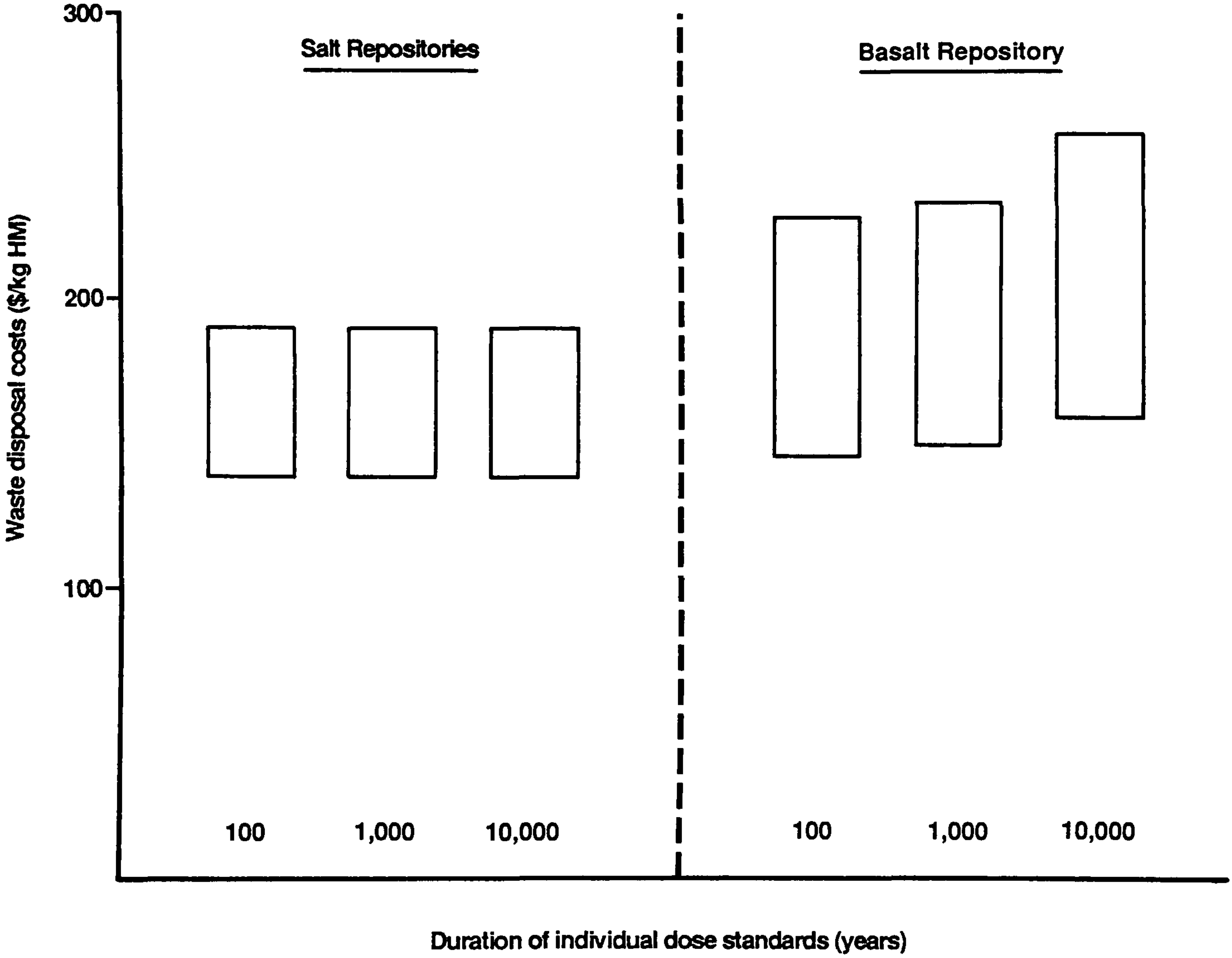


Figure 1-3. Waste disposal costs as a function of the duration of the individual dose standards assuming non-compliance with 10 CFR 60

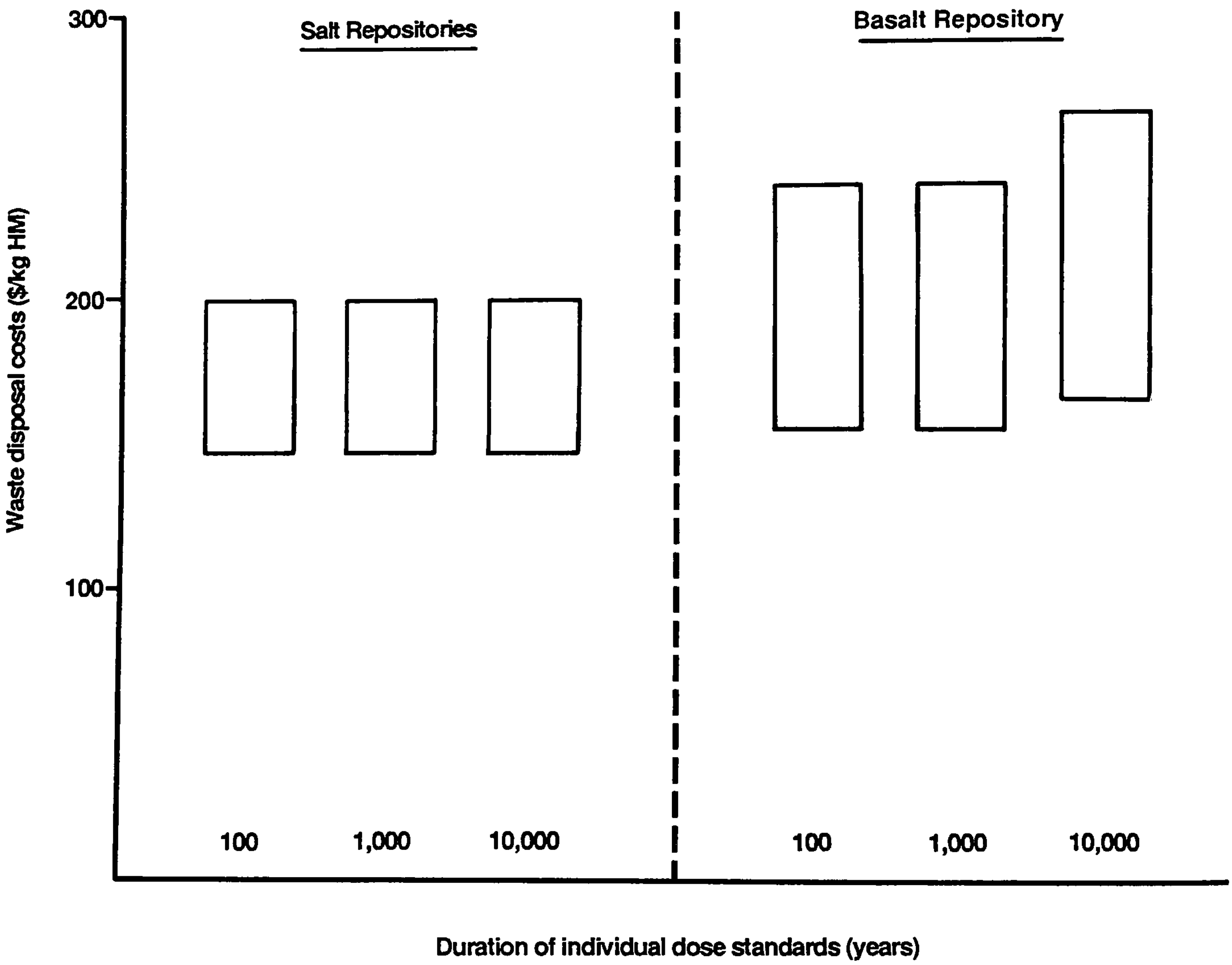


Figure 1-4. Waste disposal costs as a function of the duration of the individual dose standards assuming compliance with 10 CFR 60

1.4 Summary

These regulatory impact analyses indicate that the various disposal standards in the final rule should not cause any increases in disposal cost when compared to significantly less stringent levels of protection, assuming that the existing requirements of 10 CFR 60 are met. For geologic repositories at the two bedded salt sites considered, there appear to be no potential increases in costs even if the engineered barrier provisions of 10 CFR 60 are not taken into account. Only for the basalt site do potential cost impacts appear when neglecting 10 CFR 60, and these are relatively small: about 6 to 12 million dollars per year, a value substantially smaller than the uncertainty in the total costs for disposal of these wastes, which range between 400 and 700 million dollars per year.

Chapter 2

REGULATORY GOALS AND BENEFITS

The program to develop these environmental standards was begun as part of President Ford's Nuclear Waste Management Plan, which was announced on October 27, 1976. President Carter formed an Interagency Review Group (IRG) on Nuclear Waste Management in March 1978 to review existing policies. This group recommended that EPA maintain its responsibility to set standards for nuclear waste management and disposal and that the Agency should accelerate its programs to do so. In making its recommendations, the IRG emphasized the public comments it had received on a draft of its report:

> "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." (IRG 79)

Shortly after these standards were proposed for public review and comment (on December 29, 1982), the Nuclear Waste Policy Act of 1982 (NWPA) was signed by President Reagan on January 7, 1983. The NWPA reiterated EPA's responsibilities to develop these standards and called for their promulgation by January 7, 1984. The Agency did not meet this deadline, and the Natural Resources Defense Council and four other environmental interest groups brought suit in February 1985 to compel compliance with the NWPA mandate. This litigation was resolved when the Agency and the plaintiffs agreed to a consent order requiring promulgation not later than August 15, 1985.

This brief history illustrates the general consensus that creation of appropriate environmental standards is a necessary preliminary step in the national program to develop and demonstrate disposal systems for spent nuclear fuel and high-level radioactive wastes. The Agency began its program to develop these standards by planning a series of public workshops that were conducted in 1977 and 1978 to better understand the technical issues and public concerns surrounding disposal of these dangerous materials. Based on the outcome of these workshops and its subsequent studies and interactions with the public, the Agency has formulated the following interrelated regulatory goals that are addressed by 40 CFR 191:

(1) To ensure very good long-term isolation of these wastes from present and future populations. Although these wastes are produced in relatively small quantities, they are much too dangerous to disperse in the environment. Therefore, the primary disposal standards in 40 CFR 191 are quantitative containment requirements that limit projected releases from these disposal systems over 10,000 years to levels that appear reasonably achievable

through the current program and that provide ample protection of public health and the environment. The containment requirements apply to potential releases from expected performance of the disposal system and to a wide range of possible disruptive events as well.

(2) To limit the potential risks caused by the uncertainties inherent in designing disposal systems that must keep releases very small for such a long time. The containment requirements in 40 CFR 191 are complemented by six qualitative assurance requirements (and by corresponding provisions in NRC and DOE regulations) that should compensate for these uncertainties by calling for cautious procedures and design principles to be used for disposing of these wastes. The Agency believes that these qualitative requirements are important for developing the necessary confidence that the long-term containment requirements will be met.

(3) To accomplish these objectives through limited reliance on institutional controls. Because these wastes will remain dangerous for so long, the national program is based upon disposal systems that should not require long-term maintenance and surveillance by future generations. One of the assurance requirements in 40 CFR 191 limits reliance on any contributions from active institutional controls to no more than 100 years after disposal. In addition, although some potential benefits of passive institutional controls (e.g., markers, records, regulations, and other methods of passing on knowledge about these wastes) may be considered, the Agency has based 40 CFR 191 on the assumption that such passive institutional controls will periodically fail to deter inadvertent human intrusion into the disposal systems.

(4) To provide protection for future individuals in the vicinity of disposal systems that is compatible with the previous objectives. Although several of the assurance requirements serve to reduce the chances that individuals will inadvertently receive significant exposures from these disposal systems, the proposed rule did not contain any quantitative design requirements to limit individual exposures. After evaluating the comments received on the proposed rule, the Agency has supplemented the containment and assurance requirements with provisions that limit individual exposures and radionuclide concentrations in certain ground waters for 1,000 years after disposal. These new requirements apply to the undisturbed performance of the disposal system and not to potential releases from unplanned disruptions.

In the simplest sense, the benefits of these standards are the health effects and radiation exposures that might be avoided if the standards were set at less stringent levels. Such potential benefits can be quantified by comparing the alternative levels of protection considered in this RIA. For example, the benefits of containment requirements that limit long-term health effects to 1,000 premature deaths over 10,000 years--compared to requirements that would correspond to 10,000 deaths over 10,000 years--would be the 9,000 deaths avoided.

However, as explained in Chapter 4, the likely benefits from the chosen level of protection could also consider the likelihood that relaxing the standards would not actually lead to larger health risks--since many of the mined repositories being considered appear to keep projected risks well below 1,000 premature deaths by virtue of their inherent characteristics.

A more important benefit of this rule, although it cannot be quantified, should be the confidence fostered by environmental standards that require disposal of these wastes to be accomplished with very good protection of public health and the environment for many thousands of years. In turn, this confidence should enable the national high-level waste disposal program to proceed with the key steps needed to develop and demonstrate a disposal system. In the context of the program mandated by the NWPA, these steps involve identification, characterization, and comparison of potential geologic repository sites. This part of the program has been delayed for many years (dating back well before the NWPA) by a variety of non-technical problems, including State laws that restricted or prohibited disposal of high-level wastes. Eventually, once acceptable disposal systems have been developed and demonstrated, the long-term costs and potential risks of indefinite storage of these materials can be avoided.

Chapter 3

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. Further, none of these technologies has been transferred to full-scale production. Table 3-1 shows the range of costs, in units of dollars per kilogram of heavy metal (uranium or plutonium inserted as fuel into a commercial reactor), for the various elements of waste disposal considered in this analysis. This framework was assembled from three major sources (LE 80, ADL 79, and DOE 80) for the Draft RIA, and the estimates have been updated from a number of more recent studies (WA 82, EN 82, and SC 83) for this Final RIA. To avoid understating any relative cost impacts that the standards might have on the total costs of disposal, the cost estimates were generally chosen so as to minimize (rather than maximize) the range of estimates shown for each element of the total disposal cost. Unless otherwise stated, all costs are in 1984 dollars and have been converted from earlier-year dollars by using inflation factors based on the Department of Commerce Composite Construction Cost Index (BU 85).

Table 3-2 shows the same information as Table 3-1, except that the costs are now displayed as the present value discounted at two different discount rates: 2 percent and 10 percent. These discounted costs have been included in response to one of the comments of the SAB panel that reviewed the technical basis for the proposed rule. The relative effect of different types of disposal standards will vary for different discount rates because some of the costs potentially affected by the standards occur at different times during the process of selecting, building, and operating the high-level waste disposal system. To assess this variation over time, it was assumed: (1) that the earliest costs (for research and development) began to accrue in 1982; (2) that two repositories are constructed and begin accepting waste by 1998; (3) that these two repositories continue accepting waste until 2027--by which time they will have accepted all the high-level waste projected to be generated by 2014; and (4) that these repositories are decommissioned over the years 2028 through 2032. This time line ignores the fact that one of the two geologic repositories called for by the NWPA should start accepting wastes a few years before the other, and it assumes that the national program will overcome delays that have been encountered to date and will begin disposing of waste by the 1998 deadline set by the NWPA. However, these simplifying assumptions should not significantly affect the conclusions drawn from this RIA.

The following paragraphs discuss the cost estimates for each element of the waste disposal costs, with particular attention to the four elements that might be affected by the disposal standards. In all cases, costs are stated in terms of dollars per kilogram of heavy metal ($/kg HM). This is a commonly used unit of cost for waste management and disposal, and it allows comparisons

Table 3-1

TOTAL COSTS OF WASTE MANAGEMENT (1984 DOLLARS)

Cost element	Probable* range ($/kg HM)
STORAGE	--not considered in Final RIA
TRANSPORTATION	24 - 33
ENCAPSULATION (Canister)	6 - 15 **
WASTE FORM	10 - 20 **
REPOSITORY CONSTRUCTION AND OPERATION	64 -120 **
RESEARCH AND DEVELOPMENT	28 - 34 **
GOVERNMENT OVERHEAD	3 - 11
DECOMMISSIONING	4 - 6
TOTAL	139 -239

*Range of costs judged to be likely for the national program (excludes parts of the ranges shown below that probably will not be incurred).

**Cost elements which might be affected by the standards:

			$/kg HM (1984 dollars)
Assumptions about canister costs:	very good	=	20 - 40
	good	=	10 - 15
	minimum	=	6 - 10
Assumptions about waste form costs:	very good	=	14 - 20
	good	=	12 - 18
	minimum	=	10 - 16
Assumptions about repository construction costs:	salt	=	64 - 80
	basalt	=	71 -120
Assumed variation of research and development costs with alternative stringency levels:	baseline	=	28 - 34
	[if risks within factor of 10 of standards]	=	42 - 51

Table 3-2

TOTAL COSTS OF WASTE DISPOSAL (1984 DOLLARS)

Cost element	Undiscounted costs ($/kg HM)	Present value* discounted at 2%/yr	Present value* discounted at 10%/yr
STORAGE	-- not included in Final RIA --		
TRANSPORTATION	24 - 33	13 - 18	1.8 - 2.5
ENCAPSULATION (Canister)	6 - 15**	3 - 8	0.5 - 1.1
WASTE FORM	10 - 20**	5 - 11	0.8 - 1.5
REPOSITORY CONSTRUCTION & OPERATION	64 -120**	38 - 72	8.4 - 15.8
RESEARCH AND DEVELOPMENT	28 - 34**	24 - 29	14.6 - 17.7
GOVERNMENT OVERHEAD	3 - 11	2 - 6	0.2 - 0.8
DECOMMISSIONING	4 - 6	2 - 2	0.1 - 0.1
TOTAL	139 -239	87 -146	26.4 - 39.5

* Some ranges may be affected by rounding approximations.

** Cost elements which might be affected by the standards:

		$/kg HM (1984 dollars) discounted at: 2%/yr	10%/yr
Assumptions about canister costs:	very good =	11 - 22	1.5 - 3.0
	good =	10 - 15	0.8 - 1.1
	minimum =	6 - 10	0.5 - 0.8
Assumptions about waste form costs:	very good =	8 - 11	1.1 - 1.5
	good =	7 - 10	0.9 - 1.4
	minimum =	5 - 9	0.8 - 1.2
Assumptions about repository construction costs:	salt =	38 - 48	8.4 - 10.6
	basalt =	43 - 72	9.4 - 15.8
Assumed variation of research and development costs with alternative stringency levels:	baseline =	24 - 29	14.6 - 17.7
	[if risks within factor of 10 of standards] =	36 - 43	21.9 - 26.6

of the cost of disposing of spent fuel or different forms of high-level waste from reprocessing plants. When used to describe disposal after reprocessing, the unit $/kg HM does not mean that the heavy metal itself is being disposed --since the basic objective of reprocessing spent fuel is to recover and reuse the unfissioned uranium and plutonium. Rather, the waste resulting from the processing of the spent fuel containing the heavy metal is disposed of. For each cost element, the anticipated distribution of cost over time is also shown to support the analyses of discounted costs.

3.1 Storage

The Draft RIA included waste storage as part of the costs of waste management and disposal. The SAB panel recommended that storage costs not be considered because they were not affected by the disposal standards and because their inclusion tended to reduce the relative (i.e., percentage of total cost) effects of different types of disposal standards. The Agency agrees with this recommendation, and the Final RIA considers only waste disposal costs, eliminating the costs of storage from consideration.

3.2 Transportation

For an average shipping distance of 1,500 miles, including security precautions, Engel and White (EN 82) estimate $27/kg HM for transporting spent fuel and $23/kg HM for reprocessed solidified wastes (in 1982 dollars). These estimates were based on a blend of rail and truck shipments. Using the larger of these figures (since transportation of spent fuel should predominate), correcting for inflation up to 1984, and allowing for uncertainty in these estimates, this RIA considers transportation costs to range from $24 to $33/kg HM. These costs are assumed to be evenly distributed over the time period that the repositories are accepting wastes for disposal (1998-2027).

3.3 Encapsulation (Canister)

The encapsulation cost element is the first of the four that may be affected by the disposal standards. Unlike the transportation category, the type of canister used to contain the wastes can affect the long-term performance of a repository. Thus, the costs of using canisters of three different qualities were estimated. These three categories are described in Table 3-3.

Waddell, et al. (WA 82) assume the canisters for the standard, long-lived "Westinghouse Package" (steel clad with TiCode-12) cost $8/kg HM for spent fuel and $6/kg HM in 1982 dollars for solidified reprocessed waste. This RIA conservatively assumes that these canisters correspond only to the minimum performance category shown in Table 3-3. To meet the requirements of 10 CFR 60, it is assumed that the extra materials and fabrication costs needed to make these canisters out of stainless steel and/or titanium would bring the total canister cost to $10 to $15/kg HM. Finally, the RIA considers the costs of canisters that might be likely to last up to 10,000 years. The thick copper canisters considered in the Swedish "KBS" study (KBS 78) are assumed, with materials costs that would raise the overall canister costs to at least $20 to $40/kg HM. Even these canisters would not be likely to last for so long in the relatively corrosive environment of a salt repository--but, as

Table 3-3

PERFORMANCE CATEGORIES AND ASSUMED COSTS FOR WASTE CANISTERS

Very good	=	canister lifetime approaches 10,000 years; KBS-style copper canisters are assumed to be required. Estimated engineering cost = $20-$40/kg HM.
Good	=	canister that would last several hundred years in salt repositories and 1,000 years or more in hard rock repositories--stainless steel canisters would probably be adequate. Estimated engineering cost = $10-$15/kg HM

[NOTE: NRC's 10 CFR Part 60 requires a waste package lifetime of 300 to 1000 years.]

Minimum	=	canister that would last 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 = $6-$10/kg HM.

will be seen in Chapter 4, such long-lived canisters do not appear to be needed in a salt repository under any circumstances. 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 judgment. The costs of the cansiters are assumed to be incurred evenly over the period of waste acceptance (1998-2027).

3.4 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, no published studies are available that 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.

Recent Rockwell Hanford projections (SC 83) provide a figure of $15/kg HM (1984 dollars) for a defense-waste-to-glass operation in a new plant designed for 180-day-cooled irradiated fuel. This estimate is used as a basis for the Good waste form described in Table 3-4, although it is possible that this type of glass waste form will meet the 10 CFR 60 requirements (which would then categorize it as a Very Good form in Table 3-4). An Arthur D. Little study (ADL 79), a DOE study (DOE 80), and another comparative study (JA 81) all conclude that the costs of different waste forms do not vary substantially from one type to another, and the variation that is expected will generally be less than the overall uncertainty in the cost of any specific waste form. To allow for the potential costs of requiring better waste forms in this RIA, Table 3-4 shows the judgments made about the costs of waste forms better and worse than those studied by Rockwell Hanford. The data available for consideration is summarized in Table 3-5. The $2/kg HM gaps between these three ranges probably overestimates the differences in the costs of various waste forms. As for the canisters, the costs of the waste form are assumed to be incurred evenly over the period of waste acceptance (1998-2027).

3.5 Repository Construction and Operation

This is the largest single category of costs for waste disposal. The primary uncertainties in these estimates result from the various degrees of uncertainty concerning costs of mining in the various geologic media. The data of Engel and White (EN 82) have been used to arrive at the ranges of repository construction and operation costs shown in Table 3-6 in 1982 dollars. The decommissioning costs included by Engel and White have been subtracted for Table 3-6 because these costs are considered separately in this RIA. About one-third of the costs shown in the table are assumed to be for capital construction occurring over the period 1993 through 2001. The rest are operating costs occurring more or less uniformly over the operational period from 1998 through 2027. These costs were converted to 1984 dollars for use in Table 3-1.

Table 3-4

PERFORMANCE CATEGORIES AND ASSUMED COSTS FOR WASTE FORMS

Very good	=	10^{-6} - 10^{-5} parts per year (ppy) leach rate; attainable if ongoing technology development programs are successful. Estimated engineering cost = $14 to $20/kg HM.
		[NOTE: NRC's 10 CFR Part 60 requires a long-term waste form release rate no worse than 10^{-5} ppy.]
Good	=	about 10^{-4} ppy leach rate; attainable by glass technologies already developed and by spent fuel without any special packaging. Estimated engineering cost = $12 to $18/kg HM.
Minimum	=	about 10^{-3} ppy leach rate; clearly attainable by glass technologies and spent fuel, might be attainable by very simple waste forms, such as calcines. Estimated engineering cost = $10 to $16/kg HM.

[NOTE: Available data indicates that cost variations between the different waste forms now being developed is only about $2 to $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 in Table 3-5.]

Table 3-5

COST INFORMATION OF WASTE FORMS

Cost	Source	Comment
$8 to $15/kg HM (1977 dollars)	ADL 79	Range excludes a low value of $4/kg HM
$10 to $13/kg HM (1978 dollars)	DOE 80	
$16 to $18/kg HM (1979 dollars)	JA 81	Considered some relatively sophisticated metal-matrix waste forms.
$15/kg HM (1984 dollars)	SC 83	Based on defense waste-to-glass conversion with 180-day-cooled fuel.

Table 3-6

REPOSITORY CONSTRUCTION COSTS (EN 82)

	$/kg HM (1982 dollars) for:	
Geologic media	Spent fuel	Reprocessed waste
Salt	65 - 77	62 - 70
Basalt (taken to be similar to tuff)	68 -115	68 - 99

3.6 Research and Development

Engel and White also summarize research and development cost estimates in their report. These include costs of site identification, site characterization, site approval, construction authorization, a testing facility, technological development, and related programs. Stating their estimate on an annual basis, correcting for inflation, and allowing for uncertainties produces a range of $28 to $34/kg HM (1984 dollars). The incidence of these costs over time is assumed to be as follows: 53 percent from 1982 through 1989; 42 percent from 1990 through 2000; and the remaining five percent from 2001 through 2006. As expected, this distributes the research and development costs towards the earlier years of the program far more than any other cost element.

Since the Draft RIA was prepared, DOE has identified nine potential sites for the first high-level waste repository, and the Agency's performance assessments offer no reason to think that more or better sites need to be identified to meet the disposal standards. Thus, the possibility that different disposal standards could cause more or less effort to identify sites no longer seems relevant. However, the costs of demonstrating compliance with the standards at a particular site might be significantly increased if there did not appear to be a substantial margin between the standards and initial estimates of projected performance. This RIA represents such costs by assuming that the costs of research and development are increased by 50 percent if the Agency's performance projections for a particular disposal system are within an order of magnitude <u>less</u> than the standards of interest. (For example, for standards based on 1,000 cancer deaths over 10,000 years, this RIA assumes the increase in R&D costs if the performance assessments indicate more than about 100 deaths--after appropriate adjustments for engineered controls and other mitigating factors. This increase was not assumed, however, if there appeared to be a cheaper way to accomplish the same margin of compliance (by making the waste form better, for example).

3.7 Federal Government Overhead and Decommissioning

Government overhead is defined as all expenses to the Federal 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 government overhead were developed in the Agency's earliest economic impact study (LE 80) and, corrected for inflation, now range from $3 to $11/kg HM. Government overhead costs are assumed to be evenly distributed over the operational life of the repositories (1998-2027). Decommissioning costs were estimated to be about four or five dollars per kg HM (1982 dollars) by Engel and White. A range of $4 to $6/kg HM has been used in this RIA, assumed to be spent from 2024 through 2032. Neither of these cost elements is likely to be affected by the level of stringency chosen for the disposal standards.

Chapter 4

DIFFERENT LEVELS OF PROTECTION FOR THE CONTAINMENT REQUIREMENTS

A number of considerations are applicable to the selection of the level of protection provided by the containment requirements (Section 191.13) of the disposal standards. In this Chapter, several assessments relevant to this selection are described, 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 repository performance; (c) the correlations between repository performance and cost relative to three alternative levels of protection (100, 1000, and 10,000 excess health effects over 10,000 years); and (d) the economic impacts of variations in the cost of high-level waste management and disposal. Throughout this Chapter, residual risks are often referred to in terms of excess health effects over 10,000 years. However, the reader should recall the caveats regarding these assessments discussed in Chapter 1.

4.1 Long-Term Performance Assessments

The long-term performance of mined geologic repositories was analyzed 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 (EPA 85). To do this, the Agency used generic models of repository sites and designs that are representative of conditions expected in several of the areas now being evaluated by DOE as potential sites for the first high-level waste repository. For this Final RIA, sites in three different areas were considered: (1) basalt flows on the Hanford reservation in Washington; (2) bedded salt formations in the Paradox formations in Utah; and (3) bedded salt formations in the Palo Duro basin in Texas. These analyses are intended to provide conservatively high estimates of the risks from repositories in these areas; more precise estimates cannot be made until specific sites have been selected and characterized in accordance with the Nuclear Waste Policy Act. However, the Agency believes that these analyses: (1) indicate the relative importance of the various parts of a repository system, and (2) provide a general understanding of the protection achievable by different combinations of engineered and natural barriers.

These performance assessments considered the excess premature cancer deaths (health effects) that might occur during the first 10,000 years after disposal. Ten thousand years was used as the assessment period for two reasons:

1. It is long enough for releases through ground water to reach the environment. If a shorter time (such as 1000 years) had been used, these estimates of harm could be deceptively low, because ground water would take at least 1,000 years to reach the environment at most sites. Choosing 10,000 years for assessment encourages selection of sites where the geochemical properties of the rock formations can significantly retard movement of radionuclides through ground water.

2. It is short enough that the likelihood and characteristics of geologic events that 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.

These assessments considered only two different geologic media: bedded salt and basalt. Of the nine sites being considered by DOE for the first repository, seven are in salt formations (four in salt beds and three in salt domes), one is in basalt, and one is in unsaturated volcanic tuff. The Agency believes that the performance projected for the two bedded-salt models considered in this RIA is probably representative of the approximate behavior to be expected of any of the seven salt sites. Analyses that the Agency has recently performed for the tuff site indicate that its projected releases should be comparable to those associated with the salt locations.

Figure 4-1 summarizes the projections of long-term population risks obtained by varying canister lifetimes and waste form leach rates while holding the other factors constant for the models of bedded salt and basalt. In evaluating these results, it should be remembered that 10 CFR 60 requires: (1) that waste packages (canisters) have lifetimes of at least 300 to 1,000 years and (2) that waste forms release radioactivity no more rapidly that one part in 100,000 per year.

Several broad conclusions can be drawn from these performance assessments. First, the geological, hydrological, and geochemical characteristics of a site can affect long-term population risks more than major changes in the engineered barriers. For example, the risks associated with using no engineered controls in one of the bedded-salt sites are approximately the same as the risks associated with using the NRC-required engineered barriers (which are fairly stringent) at the much wetter basalt site. Thus, it appears that efforts to identify a repository site with appropriate characteristics can have greater benefits than efforts to improve engineered controls.

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

Third, good engineered controls, particularly better waste forms, can overcome relatively poor site characteristics. The generic model of a basalt repository assumes that relatively large amounts of ground water are available to dissolve and transport waste. In spite of this disadvantage, our basalt model can achieve risks well below the limits set by the disposal standards _if_ the

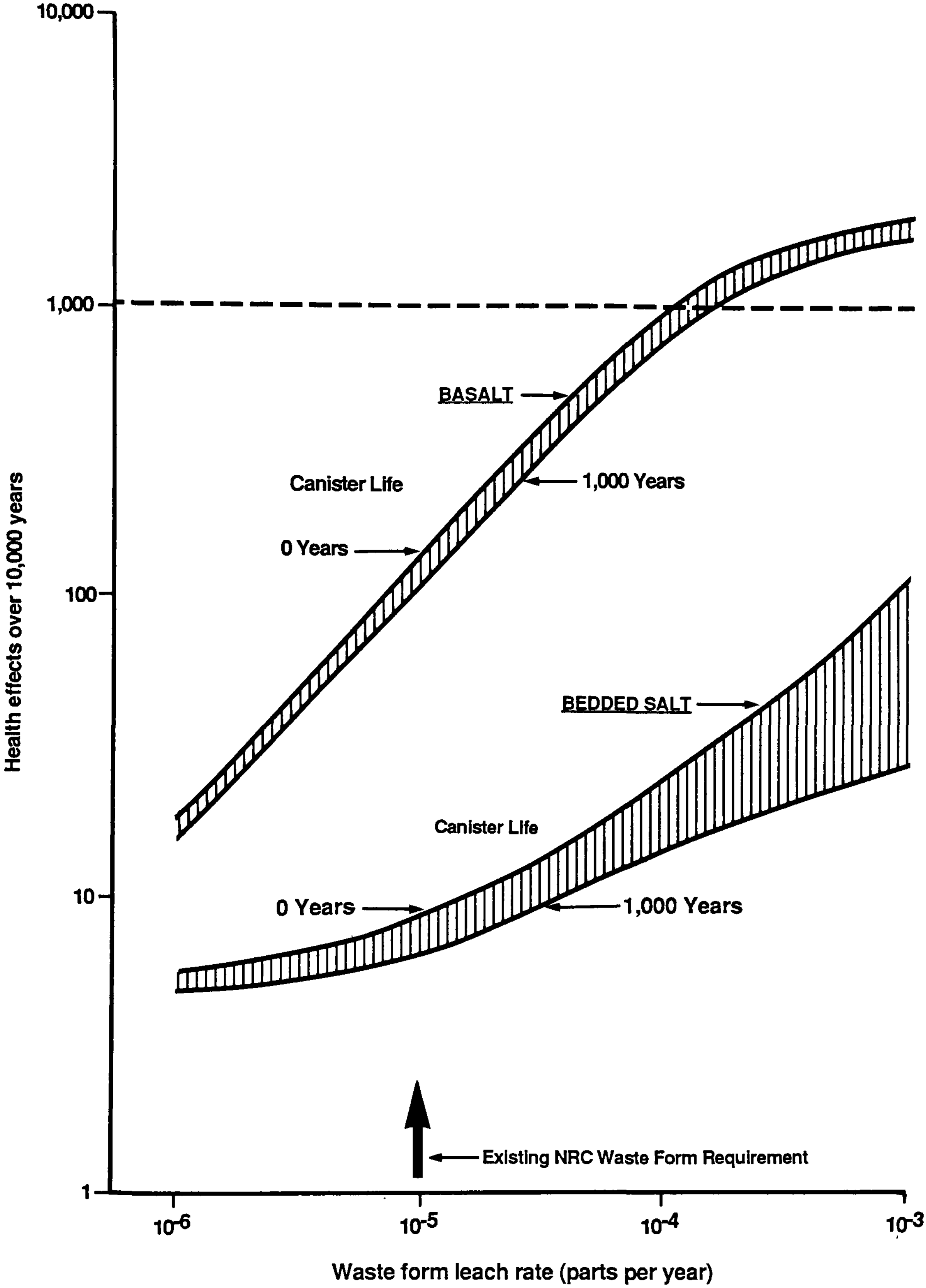


Figure 4-1. Health effects as a function of waste form leach rate

waste form used with basalt meets the criteria set forth by 10 CFR 60.

Finally, sites with very good geologic and hydrologic characteristics apparently do not need any engineered controls to meet very low risk levels. For example, the projected impacts from our bedded-salt models--which include very little ground water--do not exceed about 100 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).

4.2 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 requirements. (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 identified 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 4-2 indicates the relative incidence of the residual risks over time from the three model repositories considered in this RIA, assuming compliance with the engineered barrier requirements of 10 CFR 60 (a 300-year canister lifetime was assumed for the salt media, a 1,000-year lifetime for the basalt repository model and a waste form release rate of 10^{-5} per year). All three of these models would easily meet the release limits associated with 1,000 health effects. In fact, the expected health effects are only about 8 for the salt models and 140 for the basalt model. For the basalt model, very little of the residual risk occurs in the first 1,000 years.

Each of the models was then changed in different ways to allow the risks to rise to approximately 1,000 health effects over 10,000 years. For the model salt repositories, we assumed that the solubilities of all radionuclides in ground water were unlimited. For the basalt repository, we assumed poorer quality engineered barriers than those called for by 10 CFR 60. Figure 4-3 shows the relative incidence of the increases in the residual risks that occur in going from the results of Figure 4-2 to the larger residual risk level of 1,000 health effects over 10,000 years.

In general, there is no consistent pattern in the way the residual risks occur for the different models. Relaxing the isolation provided by different aspects of our model repositories results in 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 small. This illustrates a major reason for the choice of 10,000 years--rather than 1,000 years--as the time period for the disposal standards. Some of the characteristics of the models used for Figure 4-3 are considerably

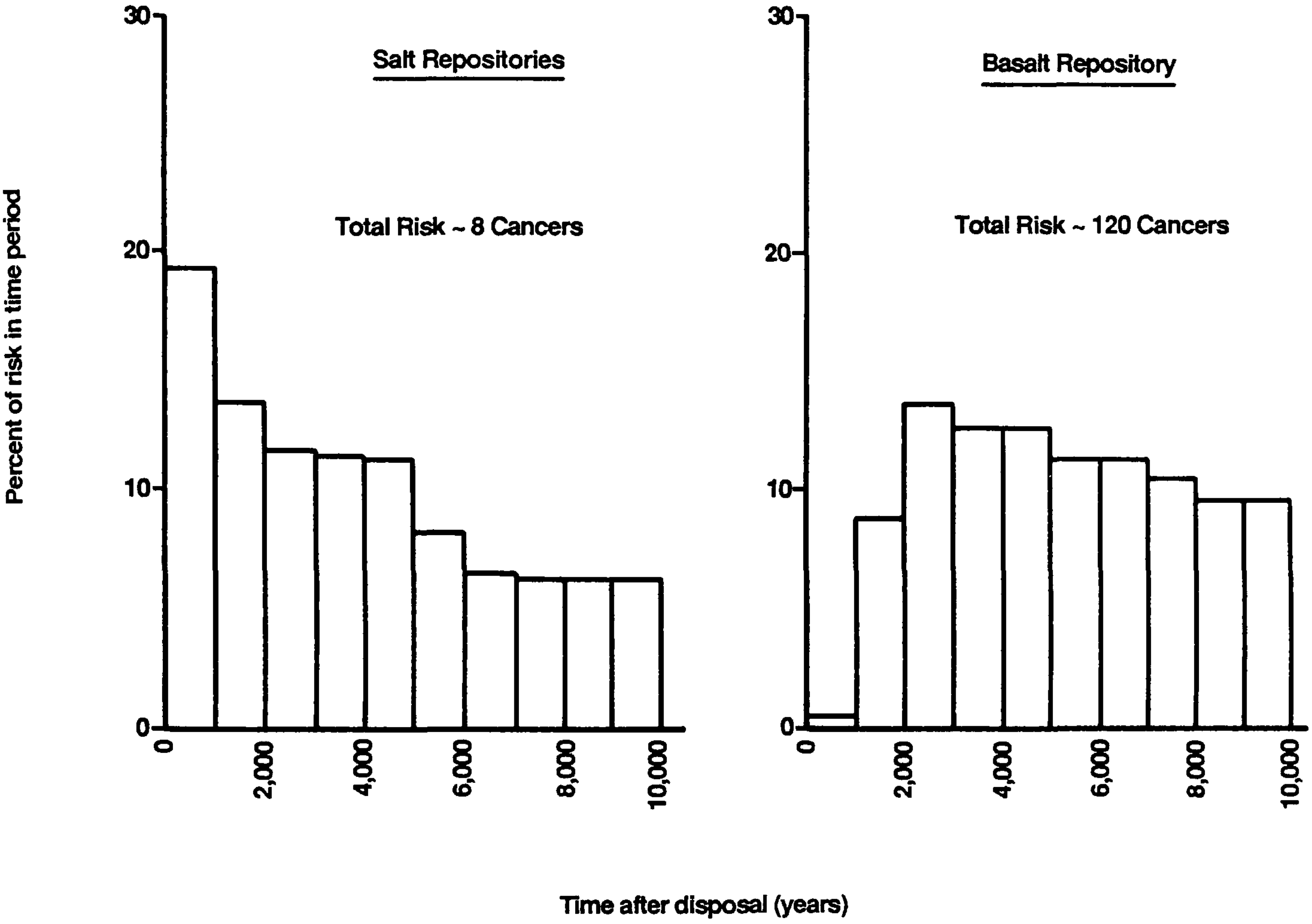


Figure 4-2. Relative incidence of residual risk for model repositories

worse than those that the Agency is confident 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 the long-term performance ramifications of major differences in site characteristics become apparent.

4.3 Engineered Control Costs and the Level of Protection

Using the analyses summarized in Section 4-1, the types of engineered barriers needed to meet different levels of protection can be assessed. Table 4-1 shows the categories of engineered controls needed to meet the various levels of protection considered for the salt and basalt model repositories. The different categories of waste forms and canisters are those discussed in Chapter 3.

The information in Table 4-1 can, in turn, be combined with the cost data in Chapter 3 to assign a range of waste disposal costs to each level of protection for each of the two media. This has been done in two ways: (1) assuming compliance with 10 CFR 60, and (2) neglecting the requirements of 10 CFR 60. Thus, any effects of the disposal standards on disposal costs can be considered independently of the NRC regulations. For example, for basalt at 1,000 health effects and ignoring 10 CFR 60, the total costs include the costs of a "good" waste form and a "minimum" canister; for basalt at 1,000 health effects and assuming compliance with 10 CFR 60, the costs include a "good" waste form and a "good" canister. (The "good" canister would be required by 10 CFR 60.) Practical requirements of handling and transportation will always require canisters and waste forms with some durability. Thus, whenever the performance assessments indicates that no engineering controls would be needed, the corresponding costs always include a "minimum" waste form and canister. Wherever only one or the other type of engineered barrier is needed, the lower cost one is selected.

Tables 4-2 and 4-3 display the variation in waste disposal costs with different levels of protection for both the salt and basalt models, with Table 4-2 ignoring the requirements of 10 CFR 60 and Table 4-3 assuming compliance. The costs of waste forms and canisters are for those indicated as necessary by the Agency's performance assessments, for those required by 10 CFR 60, or for the "minimum" canister and waste form needed for transportation and handling--whichever costs are the least for each situation. Also, extra research and development costs are included whenever the projected risks of the disposal system being studied are within about an order of magnitude of the level of protection being evaluated. These results indicate that waste management and disposal costs are not very sensitive to different levels of protection, particularly for the geologic media 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.

4.4 Economic Impacts of Different Levels of Protection

To estimate the potential economic impacts of the different costs that may be caused by these different levels of protection, the Agency first

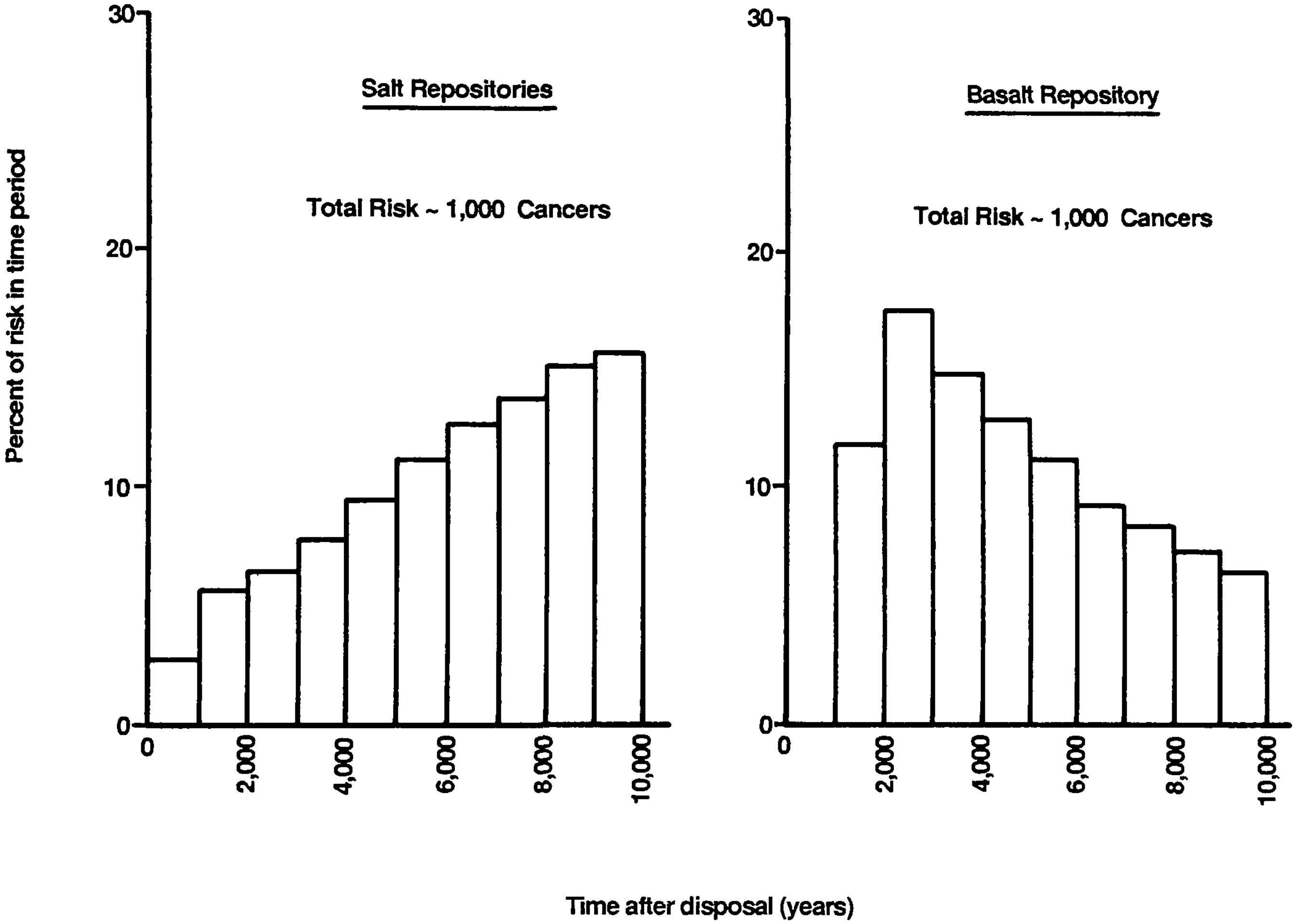


Figure 4-3. Relative incidence of increases in residual risk up to 1,000 health effects

Table 4-1

ENGINEERED CONTROLS ASSOCIATED WITH DIFFERENT LEVELS OF PROTECTION

	Level of Health Effects (over 10,000 years)		
	100	1,000	10,000
SALT	"Good" waste form or "good" canister needed	No engineering controls needed*	No engineering controls needed*
BASALT	"Very good" waste form needed (better than 10 CFR 60)	"Good" to "v.g." waste form needed (as req. by 10 CFR 60)	No engineering controls needed*

*Complete "cost savings" cannot occur since the practical requirements of waste transportation and handling will always involve canisters and waste forms with some durability.

Table 4-2

WASTE DISPOSAL COSTS ASSOCIATED WITH DIFFERENT LEVELS OF PROTECTION

[$/kg HM assuming noncompliance with the requirements of 10 CFR 60]

		Level of Health Effects (over 10,000 years)		
		100	1,000	10,000
SALT	RC&O	64- 80	64- 80	64- 80
	Encap.	6- 10	6- 10	6- 10
	W.Form	12- 18	10- 16	10- 16
	Balance	59- 84	59- 84	59- 84
	TOTAL	141-192	139-190	139-190
BASALT	RC&O	71-120	71-120	71-120
	Encap.	6- 10	6- 10	6- 10
	W.Form	14- 20	14- 20	10- 16
	ex R&D	14- 17	----	----
	Balance	59- 84	59- 84	59- 84
	TOTAL	164-251	150-234	146-230

RC&O = repository construction and operation costs
Encap. = costs for encapsulation of waste (canisters)
W.Form = costs for preparing waste form
ex R&D = extra research and development costs because projected performance would be close to level of standards
Balance = other costs, including transportation, basic research and development, decommissioning costs, and government overhead.

Table 4-3

WASTE DISPOSAL COSTS ASSOCIATED WITH DIFFERENT LEVELS OF PROTECTION

[$/kg HM assuming compliance with 10 CFR 60]

		Level of Health Effects (over 10,000 years)		
		100	1,000	10,000
SALT	RC&O	64- 80	64- 80	64- 80
	Encap.	10- 15	10- 15	10- 15
	W.Form	14- 20	14- 20	14- 20
	Balance	59- 84	59- 84	59- 84
	TOTAL	147-199	147-199	147-199
BASALT	RC&O	71-120	71-120	71-120
	Encap.	10- 15	10- 15	10- 15
	W.Form	14- 20	14- 20	14- 20
	ex R&D	14- 17	----	----
	Balance	59- 84	59- 84	59- 84
	TOTAL	168-256	154-239	154-239

RC&O = repository construction and operation costs
Encap. = costs for encapsulation of waste (canisters)
W.Form = costs for preparing waste form
ex R&D = extra research and development costs because projected performance would be close to level of standards
Balance = other costs, including transportation, basic research and development, decommissioning costs, and government overhead.

evaluated the impact of a 1-dollar increase in the cost per kilogram of heavy metal. 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 1 mil/kwh per $233/kg HM. This is slightly larger than the conversion factor DOE used in formulating the Carter Administration's spent-fuel policy, which was 1 mil/kwh per $250/kg HM (DOE 78). EPA's earliest 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 it was estimated that a charge of 1 mil/kwh would increase costs to consumers in the year 1990 by $825 million/year, assuming that nuclear power would provide 22 percent 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 1-mil/kwh charge would be $700 million/year. Combining these figures, an increase of $1/kg HM in management and disposal costs corresponds to an average annual cost increase to the nation's electricity consumers of about $3 million per year for the years 1980 through 1995.

To provide some perspective on these costs, total electric utility revenues for 1984 were about $150 billion (DOE 84). Thus, an increase in waste management and disposal costs of $1/kg HM would represent about a 0.002 percent increase in average electricity rates. Electricity generated by nuclear power plants accounted for about $20 billion of utility revenues in 1984. 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)-- or with respect to these gross revenues from nuclear-generated electricity, an increase of $1/kg HM would represent about a 0.01 percent 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 4-4.

With these conversion factors, the economic impacts of choosing different levels of protection can now be evaluated. This assessment will focus on the changes in costs between the level of protection chosen for the final rule (risks less than 1000 health effects over 10,000 years) and a level of protection ten times less stringent. As Tables 4-2 and 4-3 show, there is only one case in which disposal costs change at all between the risk levels of 1,000 and 10,000 health effects. This occurs for the basalt model when the existing requirements of 10 CFR 60 are ignored. In this situation, the extra costs for an improved waste form to meet the more stringent level with confidence are about $4/kg HM, which translates to an economic impact of about $12 million dollars per year. This same confidence could be achieved--in the structure of this model--by spending more money for site characterization (extra R&D in Table 4-2); however, this would be substantially more expensive than using a better waste form. Therefore, the step corresponding to the lesser economic impact has been assumed. This potential economic impact can also be expressed as an increase in average electricity rates of no more than 0.01 percent and an increase in the costs of nuclear power of less than 0.05 percent. Again, it should be emphasized that this nonzero impact appears for only one of the nine sites that DOE is currently considering, and then only if there is noncompliance with the NRC's existing regulations.

Table 4-4

RELATIONSHIP OF ECONOMIC IMPACTS (1984 DOLLARS) TO INCREASES IN WASTE MANAGEMENT AND DISPOSAL COSTS

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	0.002 percent per \$1/kg HM
Increase in nuclear power costs	0.01 percent per \$1/kg HM

Chapter 5

DURATION OF THE INDIVIDUAL AND GROUND WATER PROTECTION REQUIREMENTS

The models of geologic repositories in bedded salt and basalt considered in Chapter 4 were also used to assess the effects of choosing different types of individual and ground water protection requirements (Sections 191.15 and 191.16) for the disposal standards. Individual exposures from use of ground water at a distance of 2 kilometers from the edge of the repository were projected for a variety of assumptions regarding waste package lifetime and waste form release rate (EPA 85). It turns out that varying the level of stringency of these requirements over a reasonable range appears to have no effect on the costs of mined repositories. However, the duration over which these requirements are applicable can have significant impacts on the choice of geologic media and/or engineered controls. Therefore, this Chapter develops estimates of the changes in waste disposal costs for establishing the individual and ground water protection requirements over 100, 1,000, or 10,000 years after disposal.

5.1 Long-Term Performance Assessments

As in Chapter 4, sites in three different areas were considered: (1) basalt flows on the Hanford reservation in Washington; (2) bedded-salt formations in the Paradox formations in Utah; and (3) bedded-salt formations in the Palo Duro basin in Texas. Individual exposures from using ground water near the repository (at a distance of 2 kilometers) were projected for the expected ground water flow patterns at the site after the repository was built and filled with waste. Unlike the analyses used for the containment requirements, no events that could disrupt the repository or its geologic setting were considered. For the basalt repository, flow through the somewhat permeable basalt flows and the surrounding aquifers was projected, taking into account the thermal stress and temperature effects caused by the heat from the emplaced wastes. For the bedded-salt repositories, where no normal ground water flow through the salt formations is expected, ground water was assumed to flow down one of the repository shafts, along the tunnels of the mine, and then back up another shaft down-gradient from the first. Relatively conservative assumptions were made in a number of areas (particularly regarding the speed and likelihood of the ground water flow pathway for the salt repositories), which probably overestimate the amount of exposure and underestimate the time by which such exposures may begin to appear.

Figure 5-1 displays one set of results from these analyses, showing the occurrence of individual doses over the first 100,000 years after disposal. For these results, compliance with the NRC's engineered barrier requirements in 10 CFR 60 was assumed (the waste package lifetime was taken to be 1,000 years). Even with the conservative assumptions made, individual exposures do not begin to appear for the bedded salt models until well after 10,000 years. (The results for the Paradox Basin model are shown as a dotted line because the aquifer considered appears to be so small that it would not qualify for protection under Section 191.15 as a "significant source of ground water.") Therefore, setting the duration of the requirements in Sections 191.15 and

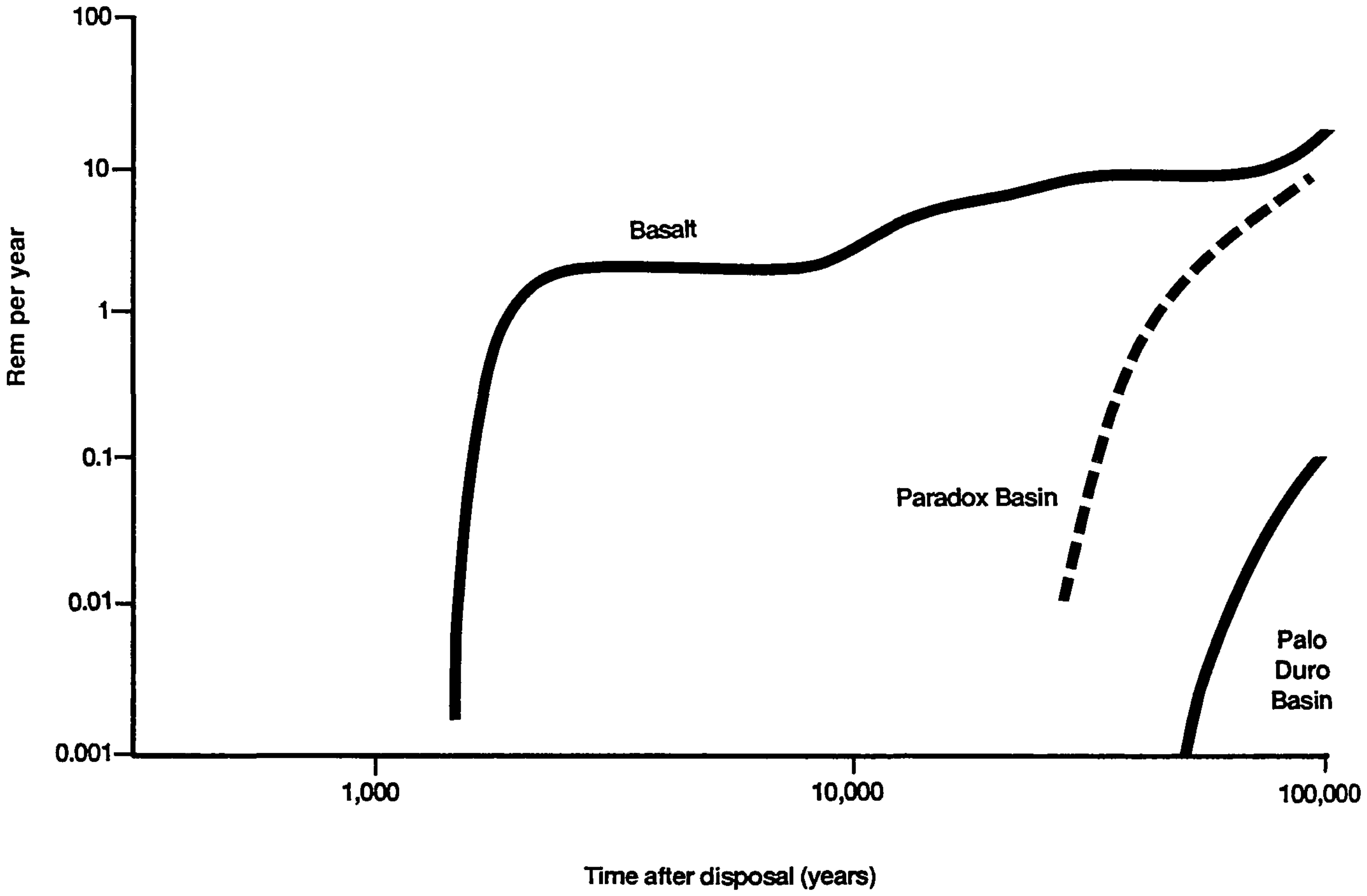


Figure 5-1. Individual doses from ground water use at two kilometers

191.16 at any of the three alternatives considered would not cause any changes in the design of these bedded-salt repositories and, hence, would not have any effect on waste disposal cost.

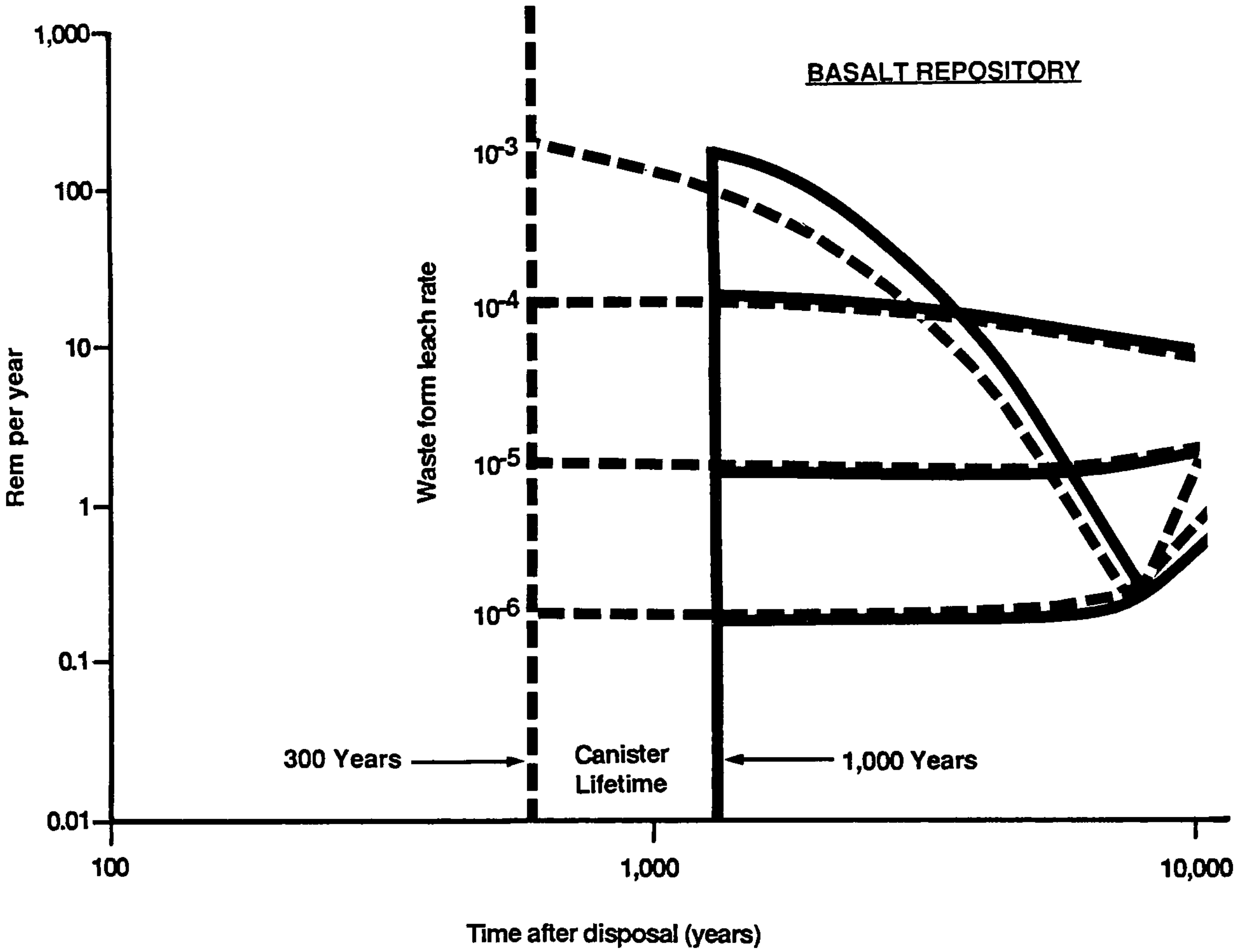
The situation for the basalt model is quite different. For the baseline analysis shown in Figure 5-1, individual doses begin to appear at about 1,500 years after disposal and quickly rise to about 2 rems per year due to migration of iodine-129 and carbon-14. They remain at this level for about 8,000 years. They then start increasing, as long-lived alpha-emitters that move more slowly through the ground water (due to geochemical retardation) begin to appear at the 2-kilometer point used in the analyses. That point was chosen because it probably will be typical of the average distance that will be established between a repository and the boundary of the controlled area).

5.2 Engineered Controls and Individual Protection

To examine the potential effects of choosing different types of individual protection requirements, the analyses for the basalt repository were repeated with a variety of assumptions about the canister lifetime and the waste form release rate. These analyses are summarized in Figure 5-2. The initial dose rate can be seen to be roughly proportional to the waste form release rate. Thus, for a release rate of no more than one part in 1,000,000 per year, the initial dose rate would be about 200 millirems per year. Since the Agency believes that this is still much higher than any reasonable dose limitation (and because this is about the best waste form performance the Agency thinks it is reasonable to project--particuarly for a spent-fuel repository), it does not appear that choosing different waste forms has any effect on the achievability of reasonable dose rate limitations. Similarly, the lifetime of the canister does not appear to have a significant effect on the dose level that can be achieved after the time that the containment provided by the canister is lost. On the other hand, the lifetime of the waste package clearly has a direct influence on the amount of time that any reasonable dose limitation can be achieved. Thus, the most sensitive variable in formulating the individual protection requirements is not the <u>level</u> of these standards, but the <u>duration</u> over which they apply. Achieving any reasonable level of protection depends upon the amount of time over which waste package integrity can be assumed. Thus, the analyses in Figure 5-2 indicate that--for the basalt model--a canister lifetime of many hundreds of years would be needed to meet a 1,000-year duration, and a canister lifetime of almost 10,000 years would be needed to meet a 10,000-year duration. (On the other hand, no canister at all appears necessary to meet either duration for the salt models.)

5.3 Engineered Control Costs and the Duration of Individual Protection

The same steps used in Chapter 4 have been used in this Chapter to assess the costs of achieving different durations of individual protection for the two media considered. Table 5-1 indicates the different engineered controls needed to achieve the three durations studied. Using the assumptions about engineered control costs developed in Chapter 3, Tables 5-2 and 5-3 display the variation in waste disposal costs with different durations for both the salt and basalt models, with Table 5-2 ignoring the requirements of 10 CFR 60 and Table 5-3 assuming compliance.



Note: There are no doses associated with bedded salt repositories within this time period

Figure 5-2. Annual individual dose from drinking ground water as a function of canister lifetime and waste form leach rate

As expected, there is no variation for the salt media, since no engineered controls of any kind appear necessary to prevent individual exposures from undisturbed performance for well beyond 10,000 years. However, there are substantial cost variations for different durations associated with the basalt model. If the requirements of Part 60 are ignored, it would cost about $5/kg HM to achieve a 1,000-year duration rather than one of 100 years (or about $15 million per year, using the economic impact factors described in Chapter 4). There are no expected additional costs for a 1,000-year duration if 10 CFR 60 is followed. To achieve a 10,000-year duration, exceptionally good canisters would be required. No such canisters have been considered in the U.S. program, so the costs of such canisters can only be a subject of speculation. However, based on the probable material costs to make the copper canisters considered in the KBS study (KBS 78), an estimate of at least $20 to $40/kg HM for these canisters has been used. This would add at least $10 to $25/kg HM to the waste disposal costs, for an annualized cost increase of $30 to $75 million per year, with a good likelihood that the extra costs would be even greater (because of quality control considerations in producing canisters expected to last almost 10,000 years). In summary, a cost increase of up to $100 million per year to achieve individual protection standards near a basalt repository appears to be a reasonable approximation.

Table 5-1

ENGINEERED CONTROLS ASSOCIATED WITH DIFFERENT DURATIONS OF INDIVIDUAL AND GROUND WATER PROTECTION REQUIREMENTS

	Duration of Requirements (years)		
	100	1,000	10,000
SALT	No engineered controls needed*	No engineered controls needed*	No engineered controls needed*
BASALT	No engineered controls needed*	Good canister needed (max req. of 10 CFR 60)	Very good canister needed (better than 10 CFR 60)

*Complete cost savings cannot occur since the practical requirements of waste transportation and handling will always involve canisters and waste forms with some durability.

Table 5-2

WASTE DISPOSAL COSTS ASSOCIATED WITH DIFFERENT DURATIONS OF INDIVIDUAL AND GROUND WATER PROTECTION REQUIREMENTS

[$/kg HM assuming non-compliance with the requirements of 10 CFR 60]

		Duration of Requirements (years)		
		100	1,000	10,000
SALT	RC&O	64-80	64-80	64-80
	Encap.	6-10	6-10	6-10
	W.Form	10-16	10-16	10-16
	Balance	59-84	59-84	59-84
	TOTAL	139-190	139-190	139-190
BASALT	RC&O	71-120	71-120	71-120
	Encap.	6- 10	10- 15	20- 40
	W.Form	10- 16	10- 16	10- 16
	Balance	59- 84	59- 84	59- 84
	TOTAL	146-230	150-235	160-260

RC&O = repository construction and operation costs
Encap. = costs for encapsulation of waste (canisters)
W.Form = costs for preparing waste form
Balance = other costs, including transportation, basic research and development, decommissioning costs, and government overhead.

Table 5-3

WASTE DISPOSAL COSTS ASSOCIATED WITH DIFFERENT DURATIONS OF INDIVIDUAL AND GROUND WATER PROTECTION REQUIREMENTS

[$/kg HM assuming compliance with 10 CFR 60]

		Duration of Requirements (years)		
		100	1,000	10,000
SALT	RC&O	64-80	64-80	64-80
	Encap.	10-15	10-15	10-15
	W.Form	14-20	14-20	14-20
	Balance	59-84	59-84	59-84
	TOTAL	147-199	147-199	147-199
BASALT	RC&O	71-120	71-120	71-120
	Encap.	10- 15	10- 15	20- 40
	W.Form	14- 20	14- 20	14- 20
	Balance	59- 84	59- 84	59- 84
	TOTAL	154-239	154-239	164-264

RC&O = repository construction and operation costs
Encap. = costs for encapsulation of waste (canisters)
W.Form = costs for preparing waste form
Balance = other costs, including transportation, basic research and development, decommissioning costs, and government overhead.

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