Chapter 3

A Systems Analysis of Superfund

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INTRODUCTION

In the Superfund program so far, more attention has been paid to short-term costs and budgets than to total program costs and program durations which can cover decades. A Superfund program designed from a short-term perspective may not be consistent with the need for long-term programs to permanently deal with the problems posed by thousands of uncontrolled hazardous waste sites. Without adequate planning, the result may be a cleanup program that extends beyond several decades, presenting uncertain and possibly serious health and environmental risks.

This chapter examines how future financial needs of the Superfund program may be assessed and what program strategy can meet these needs. A simple simulation model is presented which illustrates how cleanup *costs,* present and future, might be taken into account. The past performance of the program is considered, the uncertainty of historical costs is recognized, and alternative strategies are compared. The results indicate there will be trade-offs between program cost and the time required to mitigate the threats posed by large numbers of uncontrolled hazardous waste sites.

Finally, a two-part cleanup strategy is identified that shows promise as a sound, long-term approach to the problem, especially in the face of many uncertainties.

Current Estimates of Future Superfund Needs

Recent estimates of future financial needs of the Superfund program confirm the need for an expanded fund. The studies summarized in table 3-I estimate that the cost to clean up the Nation's uncontrolled hazardous waste sites will be substantially greater than the current fund of $1.6 billion. Their estimates range from $6 billion to $92 billion, with all but one calculating the Federal share of these costs at $5 billion to $26 billion. Only the Department of Commerce (DOC) study predicts that the current Superfund of $1.6 billion can meet requirements for cleanup. However, DOC assumed that only 546 sites would be eligible for the Fund; this estimate is already out-of-date since over 200 new sites have been proposed for listing on the current 538 site National Priority List (NPL).

Several sources of uncertainty are responsible for the wide range of estimates in table 3-1; the most important are the number of sites requiring cleanup and the costs of cleanup. Estimates for the total number of sites to be cleaned ranged from 1,400 to over 7,000. While this may appear large enough to encompass true lower and upper bounds, there is evidence to the contrary. OTA finds that a more appropriate estimate is 10,000 sites (see chapter 5), without including several categories of candidates for Superfund sites, e.g., as many as 75,000 mining wastes sites and 100,000 currently leaking underground storage tanks, projected to increase to 350,000 within the next 5 years.[1]

Similarly, estimates of cleanup costs vary a great deal, from $1 million to $30 million per site. Also, most of the predictions of total cleanup cost assumed that the worst sites, those requiring the most costly response, were captured in the current estimates of the numbers of sites. This may not be so. For example, DOC estimated that those sites not already on the NPL will cost much less to clean up than NPL sites ($3.2 million per site v. $9.7 million per

[1] Donald V. Feliciano, "Leaking Underground Storage Tanks: A Potential Environmental Problem," U.S. Library of Congress, Congressional Research Service, Jan. 11, 1984.

Table 3-1.—Current Estimates for Cleaning up Uncontrolled Hazardous Waste Sites

EPA (1984)[1]	EPA (1983)[2]	GAO[3]	Department of Commerce[4]	ASTSWMO[5]	CMA[6]	National Audubon Society
Number of sites requiring cleanup:						
1,500-2,500	1,400-2,200 23-56°/0 require groundwater response	1,270-2,546 23-56°/0 require groundwater response	546 NPL 1,250 non-NPL 41 municipal	7,113 (43 States surveyed) 1,500 most serious	1,000 (27 States surveyed) 3,681 (potential)	2,200-7,000 38-56°/0 require groundwater response
Total average cleanup costs per site (million):						
$6.7 -$13.3	$6-$12 including groundwater response	$2.25-$6.75 constr. $5.25-$15.75 constr. including groundwater response $1 .5-other costs	$9.7 NPL $3.2 non-NPL $30 municipal	$1-$6 $6 serious sites	$4-$7 studies, removal, and containment $17-$30 studies, removal, containment, and groundwater response	$8 including O&M $17 including groundwater response
Total costs (unadjusted) (billion):						
$10.0 -$33.3	***$10.3 -$20.6***	***$5.6 -$33.8***	$10.5	$14.6 -$42.7	NA	$8-$92
Total costs to Fund (billion):						
$7.6-$22.7[a]	***$8.4 -$16***[b]	***$5.3-$26***[c]	(***$1.5*** surplus)-$1.5[f]	NA	$4.5[e]	NA
Projected years to clean sites:						
NA	14 for 1800 sites	NA	10-15	16-23 if constrained by personnel 28-90 if constrained financially	NA	17-26 for 2,200 sites 53-84 for 7,000 sites

NOTES
[a]Assumes 40 to 60 percent of sites cleaned by Principal Responsible Parties (PRPs); Federal cost share is 90 percent; cost recovery is 47 percent for removals and 30 percent for remedialactions; 85 percent interest earned quarterly on previous year's balance. and 65 percent inflation on removal actions, assumed 190 per year at $75 million per year
[b]pRp lead actions deducted
[c]Assumes RPRs clean 29 to 44 percent of Sites
[d]Annual O&M costs are $3 l .500, $20,900, and $117,600 for NPL, non-NPL, and municipal Site.$ respectively
[e]Statement of E C Holmer, on behalf of the Chemical Manufacturers Association, June 13, 1984 (This estimate assumes no groundwater cleanup Also might include estimate that only 10 percent are orphan sites)
[f]Assumes 45 t. 55 percent cost recovery; 1 t. 15 percent of sites cleaned by PRPs: 6,5 percent annual Construction inflation; 5 percent annual general inflation; and 85 percent annual interest on cash balances
[g]Low estimates reflect $1.2 billion per year budget; high estimates are for $1.5 billion per year budget

SOURCES
(1) U S Environmental Protection Agency, "Extent of the Hazardous Release Problem and Future Funding Needs, CERCLA Section 301(a)(l)(c) Study, " December 1964
(2) U S Environmental Protectlon Agency, Superfund Task Force Preliminary Assessment, December 1983
(3) U S General Accounting Office, EPA's Preliminary Estimates of Future Hazardous Waste Cleanup *Costs* Are *Uncertain*, GAO/RCED-64-152, May 7, 1964
(4) U S Department of Commerce "Estimated Costs and Expenditures for Cleanup of the Natlon's Uncontrolled Hazardous Waste Sites" (draft), Feb 22 1984
(5) Association of State and Territorial Solid Waste Management Of ficials. "State Cleanup Programs for Hazardous Substance Sites and Spills," Dec 21. 1964
(6) Arthur D Little, Inc , Report to the Chemical Manufacturers" Association. "An Analysis of the Number of Inactive Hazardous Waste Sites That Will Use Superfund," July 1983
(7) National Audubon Society, Testimony of Leslie Dach before the House Subcommittee on Commerce, Transportation and Tourism, Mar 1, 1984

site), However, the Environmental Protection Agency's (EPA] recently released list of proposed NPL sites contains contaminated aquifers on the island of Oahu. Although this is only one very expensive site, it suggests that other large contaminated aquifers might be addressed by Superfund in the future.

All the studies share one common assumption in their cost estimates, however—a complete effectiveness of cleanup technology. This leads to some critical questions:

1. Should the effectiveness of cleanup technologies be considered in evaluating cleanup costs and program planning?
2. Is the assumption that these technologies are completely effective, warranted, and, if not, how should cost predictions be changed?
3, How certain are the "givens" of these predictions, namely continued use of historical cleanup technologies in the future program?

UNCERTAINTY AND THE NEED TO EVALUATE THE SUPERFUND PROGRAM

The Superfund program was established in response to an emergency situation of uncertain proportions. Both the threats and the measures to control hazardous waste sites were uncertain, but Congress decided that action was imperative. Little attention to uncontrolled toxic waste sites existed at the State level. Precedents existed for legislating and developing regulatory programs in difficult areas. Indeed, the preamble to the Resource Conservation and Recovery Act (RCRA) states that "the courts have repeatedly sanctioned . . , other EPA statutes where, as here, the Agency is implementing a complex program in an area 'fraught with scientific uncertainty where Congress has directed EPA to act quickly and decisively despite the lack of exact data'. "[2]

To resolve the many uncertainties, Congress mandated several information-gathering tasks in the Superfund legislation, such as:

- the designation of additional hazardous substances; s
- the development of notification procedures for hazardous substance spills;[4]
- the identification of all possible hazardous waste sites;[5]
- the collection of information about hazardous substances at those sites for preliminary assessments;[6]
- the establishment of the Agency for Toxic Substances and Disease Registry to establish and maintain: a) a national registry of serious diseases and illnesses and a national registry of persons exposed to toxic substances, b) an inventory of information of health effects of toxic substances, c) listing of areas closed to public or restricted in use because of contamination, and d) programs to study the relationships between exposure to toxic substances and illness; p and
- reports and studies on the experience with the implementation of the Superfund program, including one to project "any future funding need remaining after the expiration of authority" and another to determine "the extent to which the Act and Fund are effective . . ."[8]

The uncertainties and complexities connected with releases of hazardous substances are also reflected in the National Contingency Plan (NCP), which outlines the regulatory mechanisms for Federal response to these re-

[2]45 Federal Register 33088.
WE RCLA, Section 102(a),
[4]1 bid., Section 103(a),
[5]Ibid.

[6]Ibid., Section 104(e).
[7]1 bid., Section 104(i).
[8]Ibid., Section 301(a)(1).

leases. Throughout the preamble to the modified NCP, including the comments section, there is explicit mention of the need for flexibility in program design.[9] In part, the need for flexibility reflects the site-specific nature of the release and appropriate response. But flexibility was also built into the NCP "to incorporate our expanding knowledge and experience in developing remedies."[10]

In conclusion, there were both legislative and regulatory motivations to address uncertainty. In particular, Congress mandated EPA to evaluate effectiveness and project future financing requirements, and EPA, in the NCP, acknowledged the need to continue to develop and improve its program, Evaluating the effectiveness of cleanup approaches is a key step in meeting these congressional mandates.

Alternative Approaches to Projecting Superfund Needs

Projecting future funding needs of the Superfund program can be approached in two ways. A descriptive approach was used in making the estimates summarized in table 3-I. This approach assumes that the program will, for the most part, continue to operate as it has historically, using the same methods for selecting sites for remediation and implementing the same cleanup technologies. An average cost of cleanup is derived from historical data, perhaps subject to various rates of inflation. Next, the expected number of sites requiring remediation is estimated, again relying largely on examinations of past and current information, The percentage of sites requiring response in the past is applied to an updated universe of potential sites. A range of values may be assumed for these parameters, to reflect sampling errors or the inherent problems of projection, Future funding needs are determined by multiplying the estimate for average cleanup cost and the number of sites to be cleaned.

An alternative method of prediction is *prescriptive,* incorporating new information as well as historical experience, It proposes and evaluates a number of cleanup strategies, not limited to those used in the past. Each strategy is then compared to the others on the basis of evaluation criteria and a preferable strategy is selected, The cost of the preferred strategy provides projections for fund requirements, as mandated by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

The best way to evaluate the usefulness of the descriptive method, which is based on past practices, is to look at the historical performance of the Superfund program. If the program has been operating at an acceptable level of efficiency and effectiveness, if uncertainties in cost are adequately accounted for, and/or if no other alternatives exist, then the descriptive method is acceptable. The analysis below indicates that none of these conditions exists.

Historical Performance of the Superfund Program

As of September 30, 1984, the Emergency and Remedial Response Information System (ERRIS), the inventory of uncontrolled hazardous substance sites from which NPL sites are selected, contained 18,900 sites. EPA anticipates that the list will grow to between 22,000 and 25,000 sites.[11] Preliminary assessments had been conducted at 10,700 sites and site inspections completed at 3,600 sites.[12] Of the 1,700 sites scored with EPA's Hazard Ranking System, 538 have been selected for the National Priority List and an additional 238 sites have been proposed for listing.[13]

The first 2½ years of the Superfund program progressed slowly, but the pace has accelerated since May 1983. At the end of fiscal year 1982, 57 removal actions at both NPL and non-NPL sites had been initiated; after 2 more years, a total of 422 had been started. Of this total, only 17 were planned removal actions.[14]

[9] 47 Federal Register 31180-31202.
[10] 47 Federal Register 31182.

[11] U.S. Environmental Protection Agency, "Extent of the Hazardous Release Problem and Future Funding Needs, CERCLA Section 301(a)(l)(C) Study" (Washington, DC: Office of Solid Waste and Emergency Response, December 1984).
[12] Ibid.
[13] Ibid.
[14] U.S. Environmental Protection Agency, "The Effectiveness of the Superfund Program, CERCLA Section 301(a) (1)(A) Study" (Washington, DC: Office of Emergency and Remedial Response, December 1984). These statistics include CERCLA-financed, enforcement-lead, and responsible party actions.

The remedial aspects of the program, which pertain to long-term cleanups, are occurring more slowly. By the end of fiscal year 1982 only about 60 remedial investigation and feasibility studies (RI/FS) had been initiated; but by the end of fiscal year 1984, 315 RI/FSs had been started.[15] Remedial design has begun on 56 sites. Six sites have been designated as clean. Of the remedial cleanup actions currently underway or approved, most responses have been removal of hazardous materials for offsite disposal, or onsite containment, or both. Table 3-2 summarizes remedial actions taken for 24 sites.[16]

The institutional framework for responding to uncontrolled sites is in place. Despite initial problems, the program is beginning to operate more swiftly and smoothly. Many more sites have moved into the RI/FS and design study stages, As more studies are completed, more sites will move into the construction phase. However, only 30 percent of the 538 sites now on the NPL are receiving remedial cleanup attention.

It is also necessary to understand what is being done, and what the implications of current actions are for the future. Most of the cleanup actions approved so far involve removal and/or excavation, followed by offsite disposal. Although the facilities where Superfund wastes are taken are regulated under RCRA, these regulations do not assure detection and prevention of groundwater contamination. There is a strong likelihood that a number of RCRA facilities may become Superfund sites, some might even be able to qualify as Superfund sites now, and some already have.

This issue is examined in more depth in chapter 5 and leads to the conclusions that *removal followed by disposal is not an effective or efficient cleanup option, environmentally or economically,* unless removed wastes are destroyed, detoxified, treated, or stabilized in some fashion prior to redisposal.

Without the measures just specified, offsite removal will probably only relocate the hazard and transfer the risk. Furthermore, offsite removal usually leaves some (often considerable) residual surface waste in the form of contaminated soil that can threaten groundwater. Offsite removal does not address problems of groundwater already contaminated at the site. While partial cleanups have been common, source control and containment have also been used after removal to address groundwater problems, While the short-term costs of these remedial methods often compare favorably with other options, their long-term effectiveness can be greatly limited by site conditions, such as hydrogeology, rainfall, and geomorphology.[17]

Another response to groundwater contamination is to provide an alternative drinking water supply. (Note that water for other uses, such as bathing, often is not supplied even though health effects may be significant.) Sometimes this response is appropriate, for example when the alternate water is easily accessible and not too costly and when the affected population is not large. However, with groundwater now providing 50 percent of the Nation's drinking water, this can be a viable long-term alternative for only a limited number of sites. It is not an alternative for large populations. There is a limit to how many aquifers can be foresaken.

The groundwater problem is receiving attention; EPA has recently established an Office of

Table 3-2.—Summary of Remedial Cleanup Actions Approved

Cleanup actions approved	Number of decisions
Removal/offsite disposal with or without source control	14
Removal/offsite disposal with some incineration	1
Alternative water supply	3
Alternative water supply with treatment	2
Treatment (1 aeration; 1 air-stripping)	2
Source control and onsite treatment	2

SOURCE U S Environmental Protection Agency, "The Effectiveness of the Superfund program, CERCLA Section 301(a) (1)(A) December 1984

[15] Ibid.
[16] Ibid.

[17] The experience at the Stringfellow Acid Pits illustrates many of the problems that can arise with continued use of containment (see chapter 1],

Groundwater and developed a groundwater protection strategy.[18] The EPA has also acknowledged that groundwater contamination at Superfund sites has not yet been extensively addressed. When it is addressed, it will greatly increase the cost of the program,

The performance of cleanup actions during the last 4 years of the Superfund program do not support the use of the descriptive method for predicting future costs. The approved actions are weighted heavily in favor of least-cost options that are available now. While they are often called proven, the long-term effectiveness of these options is highly uncertain, and they may be ineffective even in the short term. The total costs of cleanup using these technologies are not accurately represented by the sum of their construction costs and first year operating and maintenance costs, On the contrary, these options are likely to prove costly in the long term. Additional remedial measures at the original sites or at other redisposal sites may be required as a consequence of the original cleanup technology decisions. In a sense an environmental deficit is created for future generations.

The final consideration is whether new, more efficient technologies exist or can be developed. The descriptive prediction method, relying on historical cleanup decisions, assumes little technological change or improvement. OTA has found that there are substantial opportunities to develop permanent, cost-effective cleanup technologies (see chapter 6). Many innovative cleanup technologies, ranging from methods of biological and chemical treatment to thermal destruction show great promise, but their development and demonstration are hampered by several institutional problems, including the fact that the Superfund program has not recognized their potential long-term cost effectiveness.

Thus, when the state of knowledge is considered, coupled with the experiences of the program and the potential for new technologies, it is clear that projections of the costs of the Superfund program must be based on:

- a comparison of alternative strategies; and
- future development, demonstration, and use of innovative, permanent cleanup technologies,

The desirability of defining a preferred long-term strategy becomes greater as evidence accumulates that many more sites may need cleanup. The long-term costs of traditional cleanup technologies, possibly acceptable with a relatively small number of sites, grows burdensome as the number of sites rises–with the number going as high as 2,000, 10,000, or more, Policy and planning decisions based mostly on low short-term costs may hamper program progress, if site after site deteriorates and must be recleaned, and as still more sites are discovered, Under such conditions, the total cost and time required to fulfill the Superfund mandate may become unacceptable to society,

The need to reevaluate and perhaps define a new program strategy is not a new concept. It was suggested by William Hedeman, EPA's Superfund chief:

> And it seems to me that the more fundamental question that has to be asked is whether or not the program and the structure and statutory base that has been established thus far to deal with this problem is really the most sensible way to go. Whether indeed we don't have as much of a national problem in the area of abandoned hazardous waste as we had in the 1930s and 40s in terms of flood control, or as we had in the 1970s with contaminated air and contaminated water? And we haven't inadvertently set into motion a system with a problem that is so convoluted and complex and difficult to manage that it could collapse of its own weight rather than accomplishing the results that were ever intended?[19]

[18] For more information see U.S. Congress, Office of Technology Assessment, *Protecting the Nation Groundwater From Contamination*, OTA-O-233 (Washington, DC: U.S. Government Printing Office, October 1984).

[19] "A Conversation With Superfund Chief Bill Hedeman," *The Environmental Forum*, August 1983.

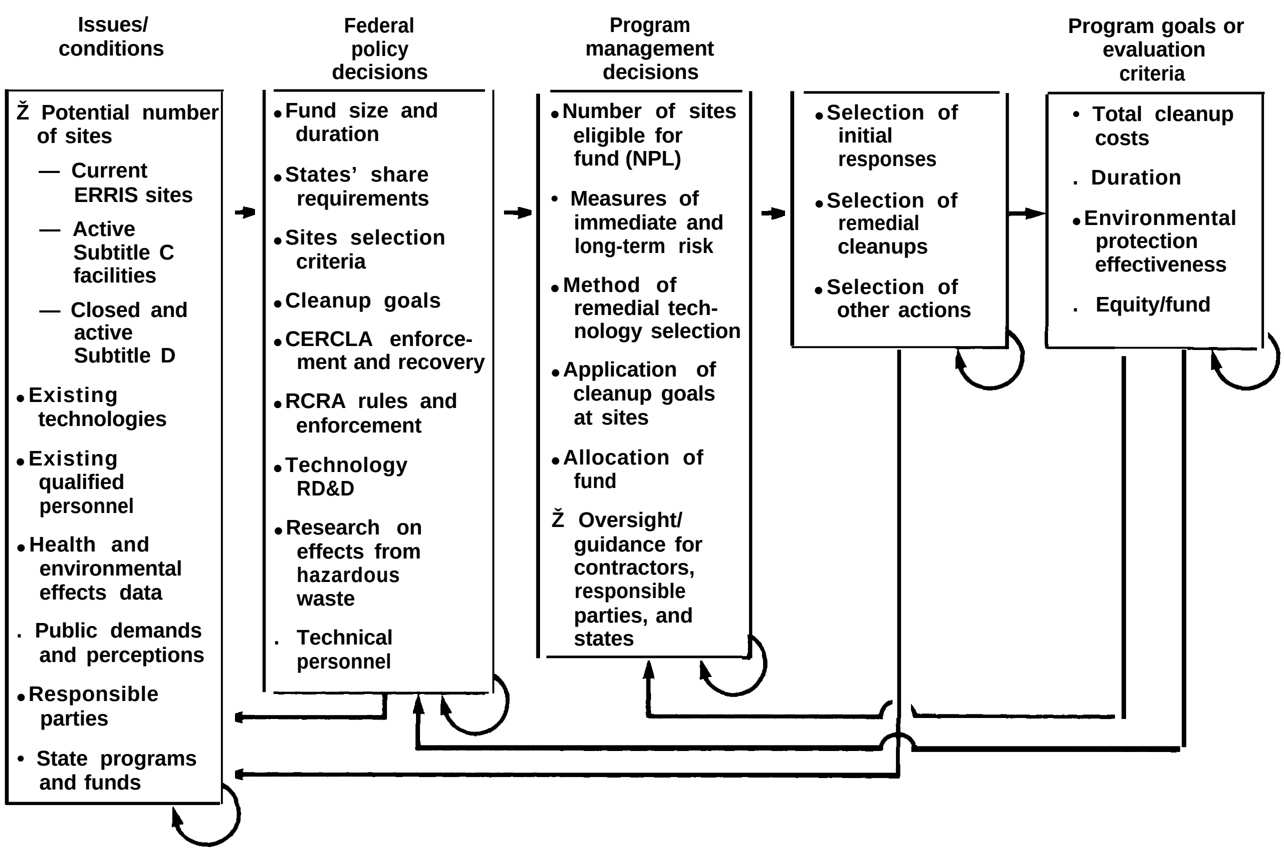
A SYSTEMS ANALYSIS APPROACH TO DEFINE A LONG-TERM STRATEGIC PLAN

Has the current Superfund program "inadvertently set into motion a system with a problem that is so convoluted and complex and difficult to manage that it could collapse of its own weight rather than accomplishing the results that were . . . intended?" The critical step toward developing a better program strategy is to realize that, in fact, the Superfund program, with its response mechanisms for threats posed by uncontrolled hazardous waste sites, is a complex system,

The Superfund system can be viewed as a series of interacting issues, conditions, and decisions. The mechanics of the system are depicted in figure 3-1. The primary inputs are listed in the box labeled issues/conditions. These include the potential number of Superfund sites, public demands and perceptions about the threats posed by these sites, and the technologies available to deal with them. All of these components affect Federal policy decisions.

Superfund policy decisions at the Federal level define an upper limit on the resources to manage the problem, provide the framework for management, and set the goals of the program, Furthermore, Federal policy dictates what sites are eligible for consideration. For

Figure 3.1 .—Superfund System



SOURCE: Off Ice of Technology Assessment instance, EPA has decided that sites with only environmental problems, which do not pose threats to human health, do not now qualify for Superfund attention, The Hazard Ranking System has no component to account for natural resource damages that do not affect human health directly. Even though Congress did not establish this policy, it did limit resources for the program.

In addition, non-Superfund policy decisions may influence the Superfund program, For example, policy changes in the RCRA program for hazardous and solid waste land disposal facilities may alter the frequency at which new Superfund sites enter the pool, depending on improvements in prevention, detection, and correction of leaks and groundwater contamination. Federal policy also affects how the financial requirements placed on the States might affect the cleanup of facilities. Many sites may fall into the 50 percent State matching share category.

Broad Federal policies are eventually translated into a program strategy via program management policies. Management decisions on ranking criteria and methodology determine which sites are included on the NPL. Program management policies also govern the allocation of resources to eligible sites and define which cleanup technologies are employed. These decisions are extremely complex because they, too, entail many interdependencies and interactions. For example, cleanup technology decisions are dependent not only on what technologies are available and at what cost, but also on the availability of funds and qualified personnel, the nature of cleanup goals, and the threats posed by uncontrolled hazardous waste sites. Management decisions by *EPA define the scope and form the strategy, even if unintentionally, of the cleanup program.*

The resultant program strategy may in turn lead to secondary, long-term consequences that also affect the system, The remedial actions alter the risks associated with the remediated sites but, if they are not wholly effective, they may impose future costs and risks. Decisions to remove and dispose of waste offsite may pose threats at other sites, which, in turn, may result in further demands on Superfund resources. Thus, current program decisions affect future system inputs and needs. The historical emphasis in the Superfund program has been on detailed site-by-site analyses, with little, if any, analysis of intersite effects. This is one reason why responses have usually entailed offsite disposal. *But cleanup on a site-by-site basis is not necessarily an effective national cleanup.* Considering each uncontrolled site independently may also lead to inconsistency; sites posing similar risks in different locations may be dealt with differently. Moreover, the long-term effects of all the interactions may not be obvious unless viewed systematically.

The complexity of the Superfund program suggests that projections of needs or changes of the program strategy should be tackled in a systems framework, using the discipline of systems analysis, With the interdependencies and interactions defined, program strategies can be evaluated more objectively and thoroughly,

Definition of Goals

An obvious Superfund objective is to minimize the cost of cleaning up uncontrolled sites. This goal raises an interesting question, namely, costs to whom? Focusing only on the costs to the Fund can lead to distortions. For instance, long-term operating and maintenance (O&M) costs are the States' responsibility. Concern with only the costs to the Fund, therefore, might emphasize cleanup technologies with lower capital costs even if the total cleanup costs will ultimately be very high (and higher than other options) because of high operating and maintenance costs. Although the current methodology used in feasibility studies for selecting remedial action does deal with O&M costs, three points should be made. First, funding estimates currently include only the initial year of O&M costs regardless of estimates made in the feasibility studies. Second, the feasibility studies often choose optimistic estimates despite limited experience with the O&M costs of the remedial technology options, Furthermore, limited experience with the application of the current technology options to hazardous waste problems coupled with undue concern about short-term costs might lead to technology decisions that fail to accomplish a long-term, permanent remedy,

Thus, to prevent distortions, all expenditures—from the Fund, from the States, and from responsible parties—must be included in the estimate of total long-term costs. This approach is highly flexible. In considering alternative or additional goals, the costs to specific parties can be derived, assumed, or compared *after* preferred solutions to the problem are generated, and the results can affect the criteria for the next iteration on the solutions.

If minimizing cleanup costs were the only goal, the solution would be to do nothing at zero cost. The goal that forces the program to operate is maximizing effectiveness in protecting human health and the environment. In the CERCLA 301(a)(l)(A) study, effectiveness is related to the "Government's ability to respond to and mitigate the effects of releases of hazardous substances, " This implies that effectiveness is the avoidance or mitigation of risks to health *and* the environment. This is the congressional mandate.

One CERCLA provision specifies that remedial actions are to be chosen that:

> . . . provide for that cost-effective response which provides a balance between the need for protection of public health and welfare and the environment at the facility under consideration and the availability of amounts from the Fund .. .[20]

According to this provision, cleanup actions are supposed to be cost effective and, at the same time, the Fund is to be allocated in a balanced fashion nationwide. The cost effectiveness criterion could be viewed as total program cost effectiveness as well as site-specific cost effectiveness. However, if affected by real or perceived budget limitations, choosing what appears to be the most cost-effective way of dealing with each site individually could reduce the cost effectiveness of the national system. *The analysis in this chapter addresses the problem of how to simulataneously achieve site and national cost effectiveness.*

The fund-balancing requirement raises a complex issue of equity, costs, and effectiveness. Furthermore, without a *reliable measure of effectiveness*, there is no way to determine whether a particular Superfund strategy is cost effective, nor can adherence to the fund-balancing provision be evaluated (see chapter 4).

Another goal that has received limited attention is minimizing *the time required to complete the program.* This goal is reflected in the idea of a mandatory cleanup schedule. The longer a site remains uncontrolled, the greater the risk may be. The risks may be the same each year and simply accumulate or they might increase over time as leaching progresses and as contaminants migrate further into the environment.

Whether or not total program length is a valid measure for risk, the public perceives it as such. For this reason, a Superfund program that emphasizes permanent cleanup actions might still pose problems if it left sites, and their affected communities, waiting for cleanup for extended lengths of time (e. g., beyond 50 years). Program length defines the planning horizon for the program and, therefore, the period over which the costs and benefits of each program strategy should be evaluated. The effects of excluding longer term costs in the planning horizon may be dramatic, as shown later in this chapter,

Such goals—proper accounting of costs over time, effective cleanup, and timeliness—can be used to evaluate different Superfund program strategies and choose among them. Because Federal and program management policies determine the cleanup strategy, the evaluation process can elucidate how these policies affect the performance of the strategy. Understanding the system dynamics can help to define how Federal policy and program management policy might change to improve program performance.

[20] CERCLA, Section 104(c)(4)

Simulation: A Systems Analysis Method for Comparing Two Strategies and Incorporating Long-Term Uncertainty

Systems analysis can be used for simulation—a model that mimics events occurring in the real system. In the context of the Superfund program, the primary event is a cleanup action. A wide range of policy and management decisions may alter the numbers, types, and rates of occurrence of the responses. These decisions can be tested using simulation for their effects on the performance of the system, In the discussion that follows, the objective is to evaluate the effects of the uncertainty in costs on program duration *after* a first site response and on total program costs under different program cleanup strategies.

Future Costs and an Impermanence Factor

The importance of examining the *effects of uncertain and unforeseen future costs* associated with a site cleanup cannot be overstated. As has been shown, effects of uncertainty about long-term costs of cleanup technologies have not been considered to any great extent, despite evidence that the technologies typically employed today may incur total costs significantly in excess of their short-term costs. Program planning based on short-term costs may result not only in an unexpectedly costly program, but in one that lasts over a very long time. It *is* particularly *important to evaluate the effects of uncertainty on long-term cleanup costs before more money is spent on costly remedial cleanups.*

An "impermanence factor" is defined to reflect the uncertainty of near-term cost estimates for response. Additional future costs, above the near-term costs of "impermanent" actions, may be incurred due to the need for additional actions, or operating and maintenance costs, or compensation for health and environmental damage. How the impermanence factor is integrated into the model differs according to the cleanup strategy chosen.

Program Cleanup Strategies

Two *extreme* cleanup strategies are examined. These *interim* and *permanent* strategies are useful as boundary conditions, clarifying the importance of certain cleanup strategies toward which the actual Superfund program could move. A third strategy, a variation of the permanent strategy and representative of the two-part plan described in chapters 1 and 2 is also analyzed.

In the interim strategy, successive interim actions, which are not permanent, are taken. Future costs are incurred and are a function of the impermanence factor and the cost of interim cleanup, In the basic permanent strategy, initial actions (with technologies and costs the same as the interim actions of the interim strategy) are undertaken for the first 15 years of the program. Like the interim responses, initial actions are impermanent, but no site receives a second impermanent action. After 15 years, cost-effective permanent technologies are assumed available; permanent cleanups are then performed on all sites, both those never responded to and those requiring a second action because of a previous impermanent action. Explicit in this strategy is the concept of concerted but limited *initial actions* with plans for *]ong-term permanent cleanup.* Future costs in this strategy are a function of the impermanence factor (from the early responses) and the costs of permanent cleanups.

Under the two-part cleanup strategy, less costly, impermanent initial actions are performed (only once) on all NPL sites until permanent cleanups are cost effective and available. As in the basic permanent strategy, after the 15-year development period, permanent actions are mandatory. In this variation, a larger number of initial actions are taken, but they are less extensive, less expensive actions, thus preserving funds for developing and implementing permanent cleanup plans. This strategy is discussed later; the model description will focus on the two primary strategies.

Model Description

In OTA's simulation model actions are undertaken annually; a particular class of actions—interim or initial—incurs future costs depending on the degree of impermanence and the distribution of costs over time.

The usefulness of the model lies not in projecting actual Superfund program costs or Superfund program duration, but rather in understanding the dynamics of the system under uncertainty. The model tells us what might happen. To correctly interpret the results of the model, the elements that characterize the system must be understood. In this modeling exercise, these elements fall into two categories: 1) system definitions and assumptions, and 2) uncertain elements to be tested.

The values of system definitions and assumptions are specified and are not varied. This is done because their behaviors and values are known with relative certainty, or the uncertainty inherent in them is not suspected to influence the aspects of the system being tested, or the effects of the uncertainty can be easily intuited. Table 3-3 summarizes the system definitions and assumptions of the model. The system definitions, such as how the budget is allocated among the different sites, relate to the system as a whole. The assumptions about parameters relate to specific cleanup actions.

The first definition given in table 3-3 is the number of uncontrolled sites eligible for the Federal fund; this figure changes as the NPL is revised periodically. Parameters such as cleanup costs and appropriate cleanup technology differed enough to warrant dividing the sites into two categories: those with only surface contamination and those with both surface and groundwater contamination. This breakdown, and the costs for each class of site, correspond to early estimates by EPA.[21] The cleanup costs, $6 million for a surface cleanup and $12 million including groundwater remedial action, include only the short-term costs of those remedial technology actions currently used. These costs, therefore, are the average costs of interim responses. The model conservatively estimates that 20 percent of the sites would require groundwater response, although more than three-quarters of NPL sites have groundwater problems,

A method of allocating a fixed annual budget (or total, unadjusted costs to all parties) to the sites is also defined. The annual budgets are distributed to surface and groundwater responses so that the same percentage of each type of site is addressed. This allocation method may be overly optimistic with regards to the attention that groundwater has received historically.[22]

Table 3.3.—System Definitions and Assumptions (not varied in model)

System definitions:
- 546 sites currently (initially) eligible for Superfund money
- Two categories of sites:
  - —Sites with only surface contamination
  - —Sites requiring groundwater response and surface response
- 20°/0 of sites eligible for Fund use require groundwater response[a]
- Each annual budget is distributed between surface and groundwater responses so that the same percentage of sites of each type are responded to annually

Assumptions about parameters to be held constant:
- Average interim action costs (estimates of currently used technologies)[b] (for interim strategy and initial action of the basic permanent strategy):
  - –$6 million/site for surface response only
  - —$1 2 million/site including groundwater response
- Average initial action costs (for two-part strategy only):
  - –$1 million/site for surface response only
  - —$3 million/site including groundwater response
- Time required to complete actions:
  - —3 years: Interim surface response
  - —6 years: Interim groundwater response
  - —3 years: Permanent surface cleanup
  - —10 years: Permanent groundwater cleanup

a 56 percent of the N PL sites exhibited groundwater contamination but only 23 percent were estimated to require treatment (U S Environmental Protect Ion Agency, *Superfund Task Force Preliminary Assessment,* Dec 8, 1984) Ground water releases have been recorded at 75 percent of the N PL sites For NPL sites where releases have not yet occurred 90 percent had potential ground water release scores over 15 and 70 percent had scores over 30 out of 45 These data suggest that this is a very conservative estimate

bA average cleanup cost of about $9 million was given in the 301(a)(l)(C) study This figure was for all types of cleanup actions (over 13 types) not accounting for States' shares, recovery and voluntary cleanup This estimate corresponds to a 50 percent rate of sites requiring groundwater cleanup

SOURCE Off Ice of Technology Assessment

21 U.S. Environmental Protection Agency, *Superfund Task Force Preliminary Assessment,* Dec. 8, 1983.

22 A statistical analysis performed on those sites for which monies were obligated prior to mid-1 983 revealed that sites with higher levels of groundwater contamination, as reflected by their HRS scores, bore a negative relationship with Fund-financed actions, See Harold C. Barnett, "The Allocation of Superfund, 1980-1 983, " Department of Economics, University of Rhode Island.

Only two NPL sites now have an active remedial program for contaminated groundwater.

Finally, because the program length is an evaluation criterion, certain assumptions about time are made. It has been estimated that the average remedial response takes 3 years to complete.[23] Since surface responses provide most of the experience, this estimate is increased to 6 years for groundwater actions. These estimates are for interim actions. Since no *permanent* cleanup has been implemented, its duration is speculative. It is assumed that permanent surface cleanups take 3 years to complete, and permanent cleanups of groundwater contamination take 10 years.

For those elements of the system that are ill-defined, different options are tested for their effects on the system. A simulation scenario is defined by choosing one option for each element. These choices are summarized in table 3-4.

Because this model could not consider site-specific data on risk and fund balancing, only total program cost and total program length are examined in any detail. Undiscounted total costs are used, but later an analysis of discounting is presented, While some of the following findings are deductive, others refer directly to particular results from the scenarios tested. Complete scenario results are given in the appendix to this chapter, along with a more detailed examination of the model.

The Interim Strategy

The primary element of uncertainty to be tested is the cleanup strategy, The interim strategy assumes no permanent cleanup technology is used; thus all cleanups are interim actions and their short-term costs do not represent the total costs of dealing with the site or the wastes. Use of interim responses implies the need for involved operation and maintenance (O&M), the costs of which have not been included in the short-term costs, The possibility of subsequent and repetitive remedial actions involving additional future costs and additional O&M costs also are not included, Interim actions include offsite disposal of wastes and contaminated materials, and traditional onsite control and containment techniques.

[23] "Extent of the Hazardous Release Problem and Future Funding Needs, CERCLA Section 301(a)(1)(C) Study, ' op. cit.

Table 3-4.—Summary of Simulation Scenarios (choose one from each element of uncertainty)'

Element of uncertainty: Options

Cleanup strategy:
- Interim strategy— Interim actions result in repeated future costs.
- Permanent strategy—An interim action during the first 15 years results in a future cost, which is a permanent cleanup. Permanent cleanups start after 15 years and result in no future costs themselves.
- Two-part strategy —Less costly initial response only (not more than once per site) over first 15 years. Afterwards, if required, a permanent cleanup with no future costs.

Future costs of impermanent cleanup actions:
Impermanence factor varied between O and 1.

Average permanent cleanup costs:
1. $24 M—surface cleanup
   $60 M—groundwater cleanup
2. $12 M—surface cleanup
   $30 M–groundwater cleanup

Time distribution of future cleanup actions:
U. Future actions occur *uniformly* **over** 30 years after an interim action.
E. Future actions occur *ear/y,* i.e., 5 years after an interim action.
L. Future actions occur *late,* i.e., 30 years after an interim action,

Budget:
A. Initial period (5 yr) budget is $1.6B; growth @ 100°/0 each successive period.
B. Initial period (5 yr) budget is $1.6B; growth @ 10°/0 each successive period.
C. Initial period (5 yr) budget is $9B; growth @ 30°/0 each successive period.
D. Each period (5 yr) budget is $9B.
S. Initial period (5 yr) budget is $5B; growth @ 100°/0 for each of next 3 periods then @ 20°/0 for each successive period.

Number of new sites per year for the first 15 years:
0.0
F. 100
M. ***200***
G. 200 for years 1-5; 800 for years 6-10; and 1,000 for years 11-15.

[a] For example, scenario 1UAF has the following values option for average permanent cleanup costs, option U fo time distribution of future cleanup actions, option A for budget, and option F for the number of new sites per year The scenario is run for both strategies, the Interim and Permanent, and the impermanence factor is varied in both strategies between zero and one

SOURCE. Office of Technology Assessment

To capture future costs, the impermanence factor is used. This factor is itself uncertain, so values for the factor between O and 1 are tested in different scenarios. The impermanence factor averages the future costs of all interim actions over the whole system. (Note that the future costs of interim actions may vary widely among the individual responses, but this model can deal only with averages.) An illustration of how an average impermanence factor might be derived from various cleanup actions is given in table 3-5.

The average impermanence factor can be interpreted in a number of ways. To illustrate one interpretation, suppose each initial interim surface response, costing $6 million, has an impermanence factor of 50 percent (0.50). Then the second action required for *each* interim action will cost only $3 million per site. But this second action will also be interim, and therefore will result in a third response, at half the cost of the second, and so on. The result is a decreasing geometric series with a finite sum. That is, each interim action requires another interim action, whose cost is related to the cost of the previous action by the impermanence factor. In other words, the sites slowly approach cleanliness, or the repeated cleanup process finally becomes effective.

The second way to interpret the impermanence factor is that an interim action only has a *probability* of requiring another interim action. If required, the future action will have the same unit response cost. An impermanence factor of 50 percent (0.50], in this case, would mean that half of all interim actions require an additional interim action, In other words, out of 100 initial interim actions performed at a cost of **$6** million per site, 50 interim actions will be required at the same unit cost, These in turn will result in 25 interim actions and so forth. (As before, cleanup of the system of sites slowly becomes effective.) More complicated interpretations that explicitly incorporate long-term operating and maintenance costs could also be constructed. However, the model may underestimate such costs since they are represented as decreasing with time for impermanence factors less than 1.

Another uncertainty is the timing of future costs. Because the program ends when the expenditures stop, it is necessary to investigate a number of alternatives. One option is that the future costs of an interim action occur uniformly over 30 years after completing the action. The other options are that the future costs occur every 5 years or every 30 years, choices which represent optimistic and pessimistic estimates of the time over which interim responses are effective. (Note that interim actions are performed over time, so that the entire program lasts substantially beyond 30 years.)

The Permanent Strategy

For the permanent cleanup strategy, the model assumes that permanent remedial technologies for all types of site problems will be available in 15 years. (Some are available now.)

Table 3-5.— Illustration of How an Average Impermance Factor of 0.5 Might Arise

Cleanup actions: Type	Cleanup actions: Percent	Potential source of future cost	Sites incurring future costs: Percent[a]	Sites incurring future costs: Impermanence factor	Contribution to average impermanence factor
Partial removal (off site disposal)	10	• Future action at disposal site • Future action onsite	50	2.0	010
Partial removal (offsite disposal) plus onsite containment	40	• Future action at disposal site • Future action onsite • High O&M costs	30	1,5	0.18
Onsite containment	*20*	• Future action onsite	75	1,0	0.15
Onsite containment/treatment . . .	*20*	• High O&M costs	50	0.5	0.05
Alternative water supply or relocation of residents	10	• Future action onsite	20	1.0	0.02
			Average impermanence factor		0.50

[a]Remai rider of sites have a zero Impermanence factor

SOURCE Off Ice of Technology Assessment

Technologies that might fall into this class are discussed in chapter 6. Under this strategy, permanent cleanups become not only available but mandatory after 15 years. During the first 15 years only initial actions where an impermanence factor is applicable are used, but no future impermanent actions may follow, only future permanent actions. The number of initial actions depends on funding during the first 15 years. Therefore, the effect of different budget levels is tested. When the permanent cleanups become available, they are used on sites that have never been treated as well as sites that received initial responses. The 15-year period simulates the time needed to develop and demonstrate more cost-effective permanent cleanup technologies, as well as other efforts to improve institutional capabilities (see chapters 1 and 2).

Models and Reality

Systems models have been used in a variety of disciplines to aid in planning and decisionmaking. Some models are dependent on natural phenomena that are easily quantifiable; this facilitates the analysis of model results. Other models cannot be easily verified because they depend on difficult-to-measure phenomena, such as behavior. The strategies modeled in this analysis are of the latter type. Other models could have been chosen. Some might define the concept of impermanence differently; others might have modeled impermanence in a more complex way. To effectively use models, it is important to understand their assumptions and limitations.

A basic assumption of the interim strategy is that there is no learning from experience. This assumption leads to drastic results, As the system's average impermanence factor approaches the value 1, total program costs and duration approach infinity, The model does not represent reality at average impermanence factors of 1 or greater; in reality, program costs cannot approach infinity. The program costs may become very large, but in reality decisions will be made to stop the program—any program—from approaching infinity. The interim strategy does, however, represent a boundary condition for what the future could be. The lack of an explicit long-term strategic plan for the uncontrolled site problem, and the continued emphasis on remedial actions with substantial unforeseen future costs suggest that the interim strategy approximates current reality. The purpose of the modeling exercise is to compare a strategy that emphasizes seemingly more expensive cleanups that have low or highly predictable future costs (modeled here as zero) with one that follows the historical path. Even without such a plan, the cleanup program will evolve and improve, but how long will the process take and what will be the costs? The interim strategy gives insights into these questions by addressing the costs of not learning fast enough from experience,

USE OF MODEL AND FINDINGS

OTA has used its model to perform an analysis of Superfund, not to attempt to design a program. Thus, it is only meant to be illustrative. Other models could be devised. Following are examples of how OTA's model can be used as an aid to decisionmaking and the findings that it generates in terms of program costs and duration, Various scenarios under both the interim and permanent strategies are compared and a variation of a permanent strategy (representing the two-part strategy proposed in chapters 1 and 2) is illustrated.[24]

Question: Is it possible that after taking an interim cleanup action, each additional future interim cleanup action will cost as much or more? That is, can a given class of interim

[24]Detailed information on all components of OTA's model, the mathematical formulations, and how the results were generated can he found in the appendix to this chapter,

cleanup technologies have an impermanence factor of *1* or greater? What would happen in the long term under an interim cleanup strategy if this were true?

Findings: The experience of the Superfund program to date, although limited, suggests that it is possible that second interim actions can cost as much or more than the first interim responses.[25]

If only interim cleanup technologies are available and if each additional interim action costs as much or more than the first, the total undiscounted program cost will be infinite and the program will continue indefinitely (unless terminated). It is unlikely that this would be the case for all sites, but repeated, expensive, ineffective cleanup at even a few sites could have serious consequences for the program.

Another possibility, however unlikely, should also be mentioned: an interim technology might accomplish little besides dispersing the contamination, This might be appropriate at some sites. Eventually, with extensive dispersion, hazardous concentrations might become low enough to be regarded as acceptable or the toxic substances might degrade. If this occurred, an interim cleanup strategy with an impermanence factor of 1 or greater might result in finite program cleanup costs and length. However, attempts at isolating hazardous wastes would have to be abandoned and society would have to accept the health risks that were present *before* very low concentrations of hazardous substances were attained, Furthermore, dispersion might increase exposure.

[25]For instance, at Stringfellow an interim remedial action was taken to prevent overflow of contaminated liquid into the community of Glen Avon. The action increased the capacity of the site from about 4 million to 8.2 million gallons. However, this also "Increased the driving potential for contaminants in the residual sludges and pond alluvium to leach into the underlying groundwater. Furthermore, the addition of lime and kiln dust to neutralize materials at the site increased the volume of contaminated soil. For these and other reasons, further cleanup at Stringfellow will exceed the costs of the first interim action, (George J Trezek, "Engineering Case Study of the Stringfellow Superfund Sites," contractor study prepared for the office of Technology Assessment, August 1984,]

Question: Will an interim cleanup strategy always lead to infinite program costs and length?

Findings: As long as the average impermanence factor is less than 1, the total cost and duration of the program will be finite because additional future costs will decrease over time. Consider a case when the impermanence factors for both interim surface and interim groundwater cleanup are 5 percent **(0.05).** The first interim surface cleanups cost $6 million per site. Under the assumption that future actions are required, 5 years after each interim action, the second cleanups average **$300,000** per site. Ten years after the first action, the additional costs will be$15,OOO per site, and after **15** years, only $750 per site. So after **15 years,** for all practical purposes, a permanent cleanup will have been achieved by a series of four interim cleanups at a total cost of slightly over **$6,300,000** per site. Similarly, the long-term undiscounted average cost per groundwater cleanup would be about *$12,600,000.*

These two costs can be thought of as the per site interim cleanup costs adjusted for future costs. Just as the cost of cleanup for one site is finite, the total cleanup costs for all sites requiring remedial action are also finite. The time it will take to complete the program also will be finite but will be determined by several factors, which will be explored later. Furthermore, depending on the costs of permanent cleanups and preferences on program length, an interim cleanup strategy might be the preferred strategy.

Question: Based on evaluation criteria of total program cost (to all sources, not just Superfund) and program length, under what conditions would the interim cleanup strategy be preferable to the permanent cleanup strategy?

Findings: Many of the assumptions listed in table 3-3 may affect the values of these two evaluation criteria. But it is primarily the average costs of an interim cleanup technology class and permanent cleanup technology class, and the impermanence factor (signifying the level of future costs) that determine total program cost and length. For example:

- Under some conditions the interim cleanup strategy is clearly preferable: when future costs of interim cleanups are very low (i.e., impermanence factors are very low), and the cost of permanent cleanups is high compared to the cost of interim cleanup. If health and environmental risks do not exist or are small, it makes sense not to spend money to develop and use permanent cleanup technologies because the interim strategy costs less and the program progresses about as quickly.
- Under other conditions, the permanent strategy is preferable, Even when the costs of interim cleanups adjusted for future costs are equal to the costs of permanent technologies, the interim strategy progresses more slowly than the permanent strategy, Because greater health and environmental risks may be incurred with the longer program, the permanent strategy is preferred.
- When the adjusted interim cleanup costs are higher than the costs of permanent cleanups, program costs under the interim strategy skyrocket *and* the program progresses much more slowly. Total long-term costs and risks would be minimized by devoting resources to the development and use of permanent cleanup technologies.
- If the adjusted costs of interim cleanups are moderately lower than those of permanent cleanups, there will be trade-offs between program cost and duration; the permanent strategy will cost more but progress more rapidly, Strategy decisions would have to be made based on other criteria, most importantly the reduction or avoidance of risk, which would favor the permanent strategy.

Figures 3-2a and 3-2b illustrate how the impermanence factor influences program cleanup costs and the time to initiate 90 percent of the work[26] under each strategy, according to Scenario 1UAF. (See table 3-4 for scenario specific at ions.)

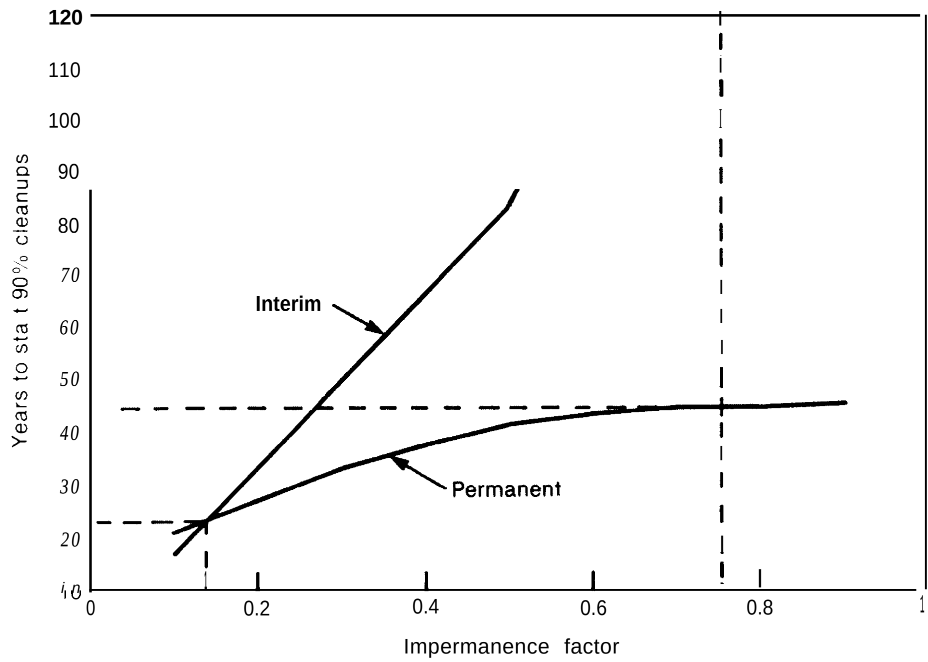
With an impermanence factor of 15 percent **(0,15),** the program length under each strategy is the same. However, at this impermanence factor the total program cost under the interim strategy is about $18 billion, considerably less than about $32 billion under the permanent strategy, Under Scenario 1UAF, then, for impermanence factors less than or equal to the relatively low value of about 0.15, the interim cleanup strategy is preferable in terms of total program cost and program length.

In contrast, in Scenario 1UAF, when the impermanence factor reaches 0.76, the total costs of both strategies are equal, but the interim strategy leads to a much longer—probably unacceptably longer—program, Cleanup takes several decades with the permanent cleanup strategy, but well over 100 years with the interim strategy, For impermanence factors above **0,76,** the interim cleanup strategy costs rise rapidly; the cost, as well as the program duration become highly unfavorable.

In the range of impermanence factors between 0.15 and 0.76, choices must be made between program cleanup cost and program length, For example, at 0.5 the permanent strategy costs $50.8 billion; under the interim strategy it is only $29.5 billion. The program length under the interim strategy is, however, **83** years, about double that of the permanent strategy (41 years), The trade-off between program duration and cost is **$507** million for each year the program is shortened. If it were worth $507 million per year to eliminate the risks in the entire system (an average of only several hun-

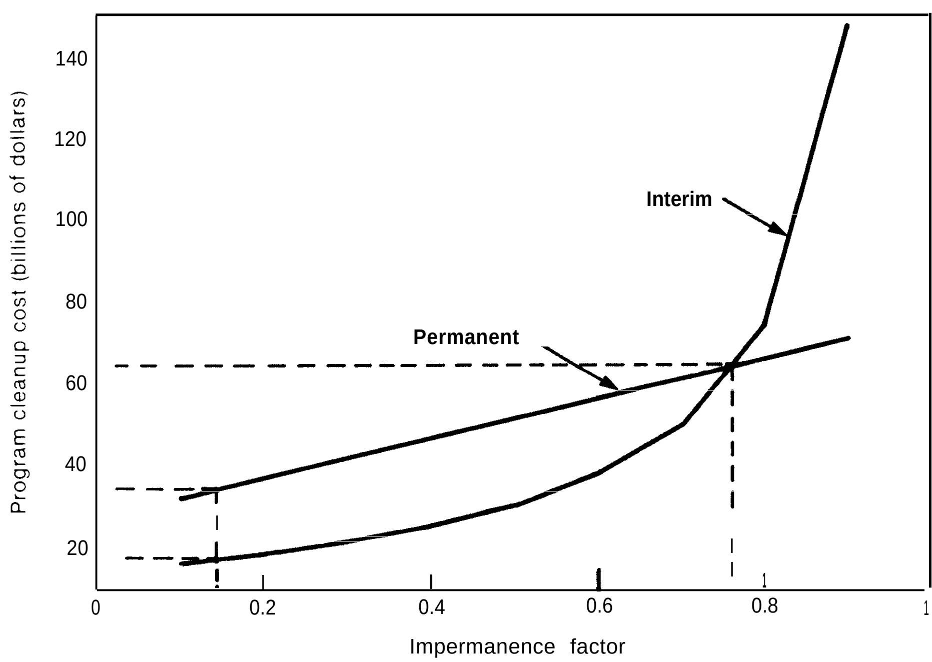
[26] For impermanence factors less than 1.(), the interi m strategy represents a decay process. Thus, a progress percentile must be used to measure program duration. The progress percentile of 90 percent, used in the findings, is the number of years after the start of the program to initiate 90 percent of all the cleanup actions ultimately required. Results for progress percentiles are found in the appendix,

Figure 3-2a.— Program Length v. Impermanence Factor
Scenario 1UAF



SOURCE Off Ice of Technology Assessment

Figure 3-2b.– Program Cost v. Impermanence Factor
Scenario 1UAF



SOURCE Off Ice of Technology Assessment

dred thousand dollars per site per year), then the permanent strategy would be preferred. Knowing the risk consequences of interim cleanups is important to an intelligent program selection.

In general, as the impermanence factor rises, the cost advantage of the interim strategy (dollars saved for each additional program year) shrinks (see table 3-6). If 50 years is judged, for example, to be the longest program the public is likely to accept, then in Scenario 1UAF the permanent strategy is always preferred for impermanence factors greater than 0.3.

Knowledge about actual future costs is vital to understanding the relative benefits of the different strategies. As it becomes clearer that certain cleanup technologies are impermanent (e.g., containment and land disposal), then the economic and environmental advantages of developing and using permanent cleanups become clearer. Only with low impermanence factors is the interim strategy advantageous.

Question: Since the costs of permanent technologies are quite speculative, how would program strategy preferences change if the average costs of the permanent technologies changed?

Findings: If the costs of permanent cleanups were to decrease, as might happen over time with experience or improvement, the permanent cleanup strategy is preferred to the interim cleanup strategy over a wider range of impermanence factors. The impermanence factor at which the costs of both strategies is equal drops, narrowing the trade-off range. In Scenario 2UAF, the cost of a permanent surface cleanup averages $12 million (versus $24 million per site as in Scenario 1UAF) and the cost of a permanent groundwater cleanup is $30 million (versus $60 million). The results of Scenario 2UAF are given in figures 3-3a and 3-3b. The point where costs are equal drops to slightly below 0.53, compared to 0.76 in Scenario 1UAF (see figures 3-2a and 3-2 b). Additionally, where trade-offs occur (impermanence factors between 0.1 and 0.53), the penalty for choosing the permanent strategy, higher program cost, is reduced.

This static analysis of two different sets of permanent costs can be extrapolated to understand the effects of permanent cleanup costs decreasing as the program gains experience (i.e., the "learning curve" effect). As cost-effective permanent technologies are used more, program costs and duration both decrease.

The opposite may occur. If the cost of the permanent cleanups were higher than anticipated, the interim strategy would be preferred over a broader range of impermanence factors and the differences in the costs of the two programs over the trade-off range would be larger.

Certainly as the costs of permanent cleanups decline, the permanent strategy becomes more appealing. If, however, permanent cleanups costs are underestimated, there is a risk of incorrectly choosing the permanent strategy.

Question: How does the budget affect cleanup strategy decisions and the evaluation criteria values under each strategy?

Table 3-6.–Scenario 1UAF

	Average impermanence factor						
	0.1	0.3	0.5	0.6	0.7	0.8	0.9
Interim *strategy:*							
Program cost (in billions)	$16.4	$21.0	$29.5	$36.8	$49.1	$73.7	$147.3
Program duration[a] (years)	17	49	83	113	>140	>140	>140
Permanent strategy:							
Program cost (in billions)	$31.4	$41.1	$50.8	$55.6	$60.5	$65.3	$70.2
Program duration[a] (years)	21				44	44	45
Trade-off[b] ($ B/year)		$1.256	$0.507	$0.269	<$0.119		

[a] Measured by the time to start 90 percent Of the cleanup work
[b] Only applied in range where tradeoffs occur

SOURCE Off Ice of Technology Assessment

Figure 3-3a. —Program Length v. Impermanence Factor
Scenario 2UAF

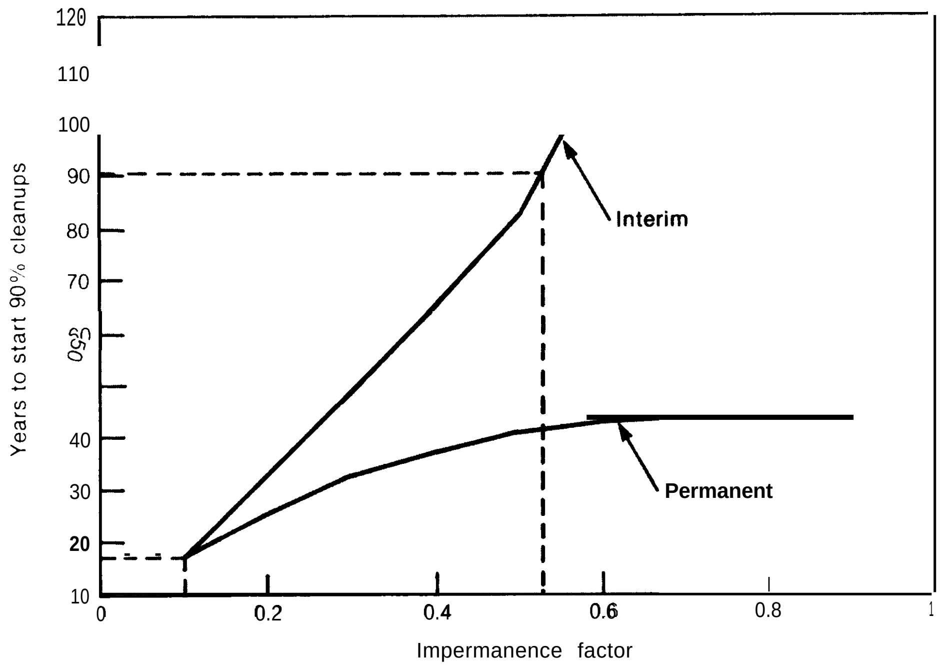


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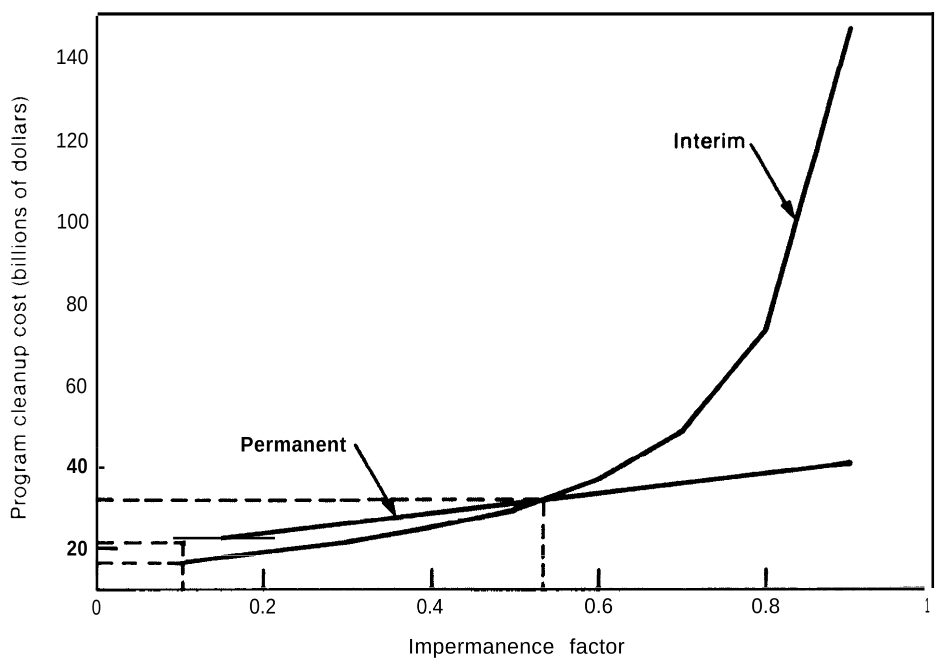
Figure 3-3b.—Program Cost v. Impermanence Factor
Scenario 2UAF



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Findings: The size of the budget (for all revenue sources, not just Superfund) devoted to cleanup activity influences cleanup strategy decisions differently,” depending on the level of the future costs of impermanent cleanups. *Inadequate budgets can bias selection toward the interim strategy and increase long-term risks from cleanups.*

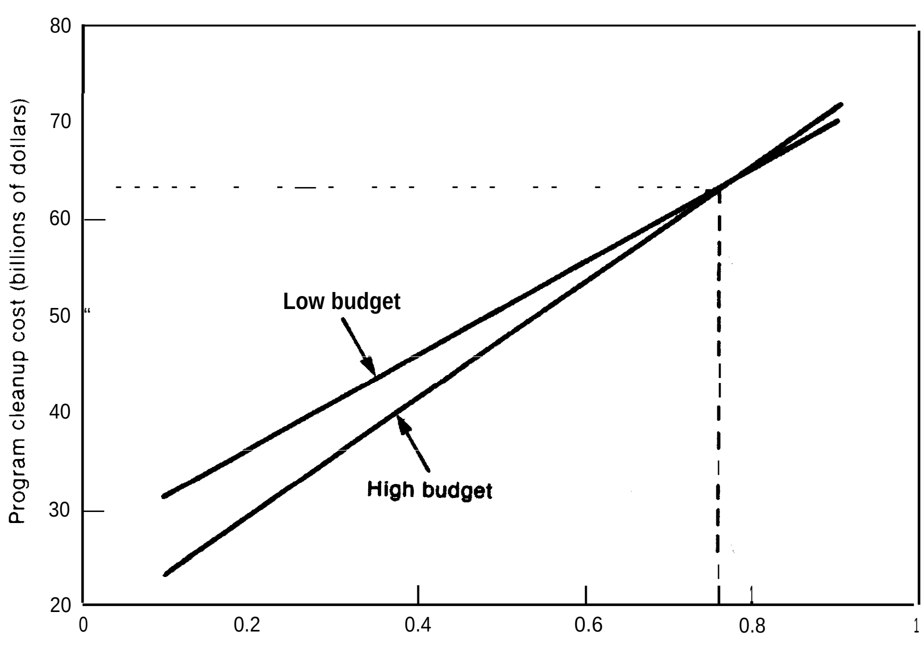
If the adjusted costs of interim cleanups are equal to or greater than the permanent cleanup costs, *then the less spent on interim cleanups when permanent technologies are being developed, the greater the program savings.*

First, consider the permanent strategy. During the first 15 years, only initial actions are undertaken. A higher budget during the early years of the program permits more initial actions and therefore results in greater total costs, The program costs under the permanent cleanup strategy with two different budget levels are compared in figure 3-4. Over the range of impermanence factors where the permanent strategy has the lower cost, program costs are greater for the larger budget scenario (Scenario 1UCF) than for the more limited budget scenario (Scenario 1UAF). While this suggests that no initial actions be taken if future costs are very high, recall that there are no explicit risk criteria in this model. It may be necessary to take some interim actions to mitigate risk when no permanent cleanup technology is available, or to consider other options, such as relocation of residents.

Now compare the interim strategy and the permanent strategy, If the adjusted costs of interim cleanups are less than those of permanent cleanups, more confidence is needed about low levels of future cost before a larger budget is devoted to interim cleanups. This makes sense: *it is desirable to be more certain about the effectiveness of a particular cleanup strategy before more money is invested in it.* The effect of increasing the annual budget is demonstrated by comparing Scenarios 1UAF (low budget) and 1UCF (high budget) in figures 3-2a and 2b and 3-5a and 5b. As the budget is increased, the interim cleanup strategy leads

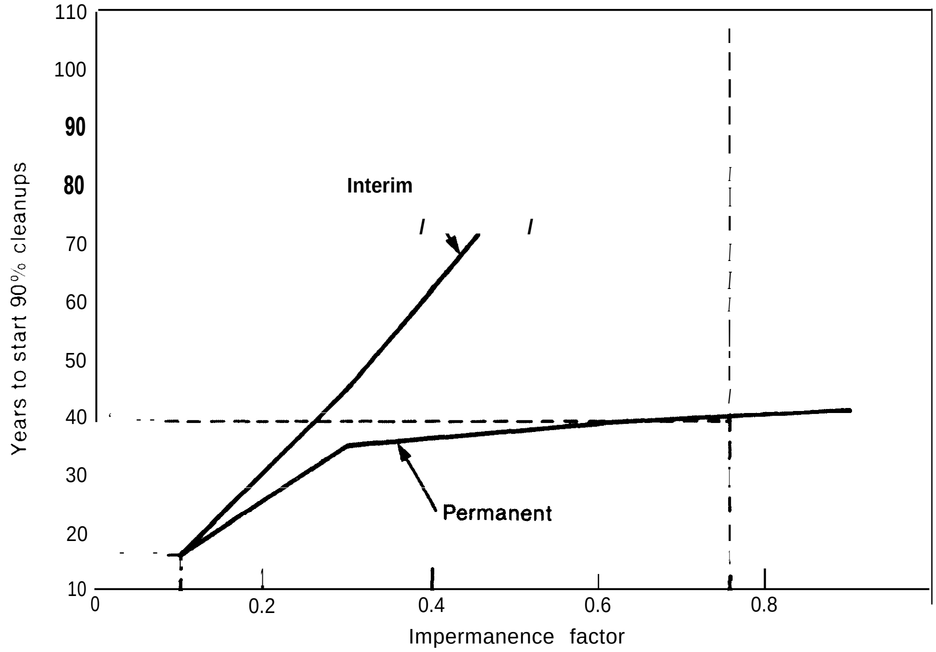
[27] Note that even though the budget continues to grow (for all options but D) through the duration of the program, after time, not all the available budget is used. Since future actions are taken only as required, as they taper off, less and less money is required.

Figure 3-4.— Program Cost v. Impermanence Factor
Permanent Strategy (Scenario 1UAF & 1UCF)



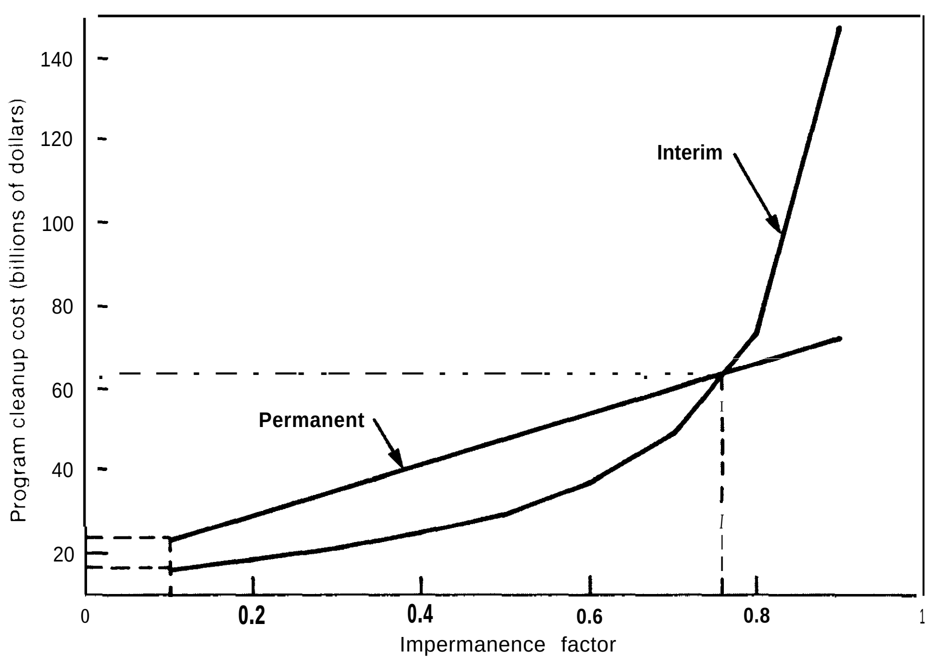
SOURCE: Office of Technology Assessment

Figure 3-5a.— Program Length v. Impermanence Factor
Scenario 1UCF



SOURCE Off Ice of Technology Assessment

Figure 3-5b.—Program Cost v. Impermanence Factor
Scenario 1UCF



SOURCE Off Ice of Technology Assessment

to a shorter program over a narrower range of impermanence factors: up to 0.15 for the low budget scenario versus up to 0.10 for the high budget scenario. The downward shift occurs because the program duration is reduced under both strategies as the budget increases.

Thus, an increased annual budget can affect cleanup strategy decisions. Similarly, reducing the annual budget also can affect the strategy decisions. In particular, *a lower annual budget (e.g., lower spending by Superfund and responsible parties) makes the interim cleanup strategy appear attractive over a wider range of future cost levels.*

Spending less on unproven technologies is a logical way to conduct cleanups where many uncertainties exist. However, this approach to strategy selection does not eliminate the uncertainty of future costs or risks resulting from program delay and inaction—it only minimizes potentially ineffective expenditures. It does not assure that the real future costs be reasonable or that the interim strategy is preferable. Furthermore, limiting this type of spending may hamper the cleanup program. Therefore, pressures to limit expenditures on cleanup *together with uncertainty resolution or alternative planning* would be preferable. One answer is to use the two-part strategy, as discussed below.

Question: Will a substantial increase in the number of sites affect cleanup strategy decisions?

Findings: As chapter 5 points out the number of sites that will require cleanup is uncertain. An increase in the number of sites will obviously increase program costs and duration; in addition, increasing the number of sites to be cleaned up exaggerates some of the above findings, Most notably, *increasing the number of sites without a comparable increase in the budget has the same effect as a more constrained budget.* The consequence is that the interim cleanup strategy is preferred, with more uncertainty in future costs (i.e., over a wider range of impermanence factors).

The program length under the interim cleanup strategy is more sensitive to the time distribution of the required future actions than to budget constraints. The converse is true of program duration under the permanent cleanup strategy; program length will be extended primarily due to budget constraints. Therefore, *an interim cleanup strategy can be made to appear more attractive than the permanent strategy by not providing enough money fast enough.*

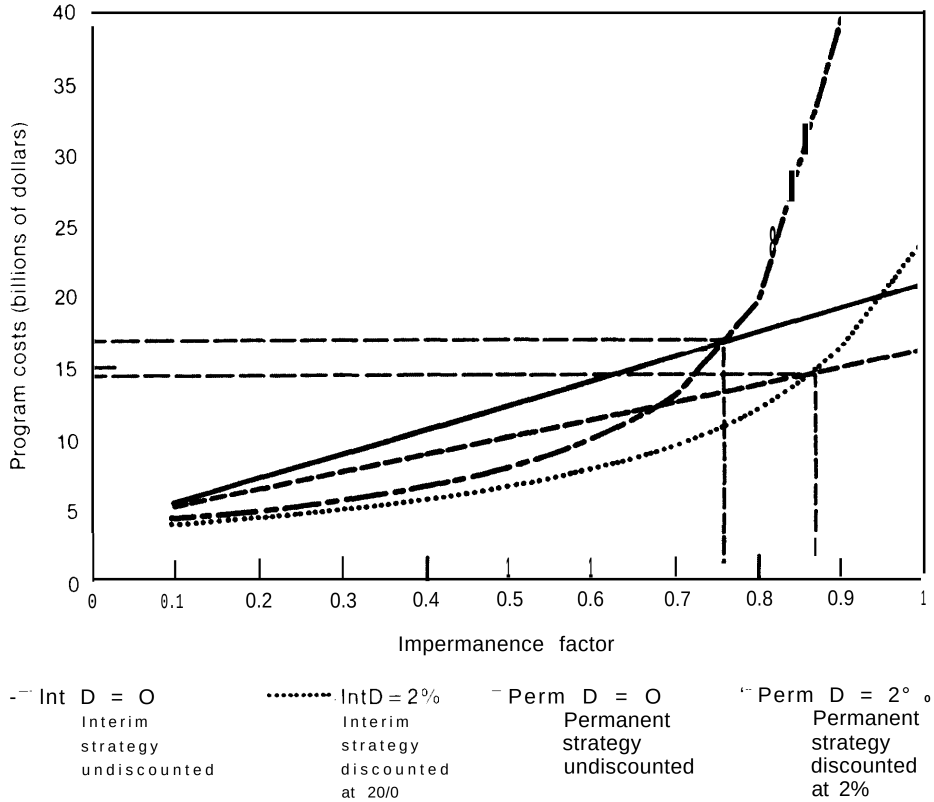
Question: How would discounting future costs affect cleanup strategy decisions?

Findings: Discounting places more weight on near-term costs and less on long-term costs. For both the interim and permanent cleanup strategies, as the impermanence factor increases, long-term costs become greater and are stretched over longer periods of time. Therefore, as impermanence increases, discounting reduces the program cost. Under the interim cleanup strategy, impermanent actions continue through the course of the program; however, under the permanent strategy, future costs result only from impermanent actions taken in the first 15 years. For this reason, the interim strategy has greater costs occurring later in the program. Thus, *program cleanup costs under the interim strategy are more sensitive to discounting than are program costs under the permanent strategy.*

Low and moderate discount rates affect strategy decisions by increasing the trade-off range between the two strategies, The application of a 2 percent per year discount rate to Scenario 1ECO is illustrated in figure 3-6. The trade-off range is extended because the impermanence factor at which the present value of both the program costs is equal is shifted higher (from 0.76 to over 0.85). Even though the range of impermanence factors over which the permanent strategy costs less is shortened, the program duration remains high so long that choosing the interim strategy is difficult to justify,

As higher discount rates are applied, a decisionmaker becomes indifferent to the two strategies in terms of cost and prefers the permanent strategy because of its shorter length. At a 10 percent per year discount rate, both strategies become almost insensitive to future cost levels. Figure 3-7 illustrates a 10 percent discount rate applied to Scenario 1ECO. Because the two cleanup strategies are similar over the

Figure 3-6. —Program Costs v. Impermanence
Undiscounted and discounted costs (Scenario 1ECO)



SOURCE Off Ice of Technology Assessment

first 15 years, at very high discount rates the present value of both program costs do not differ by much. Costs incurred beyond year 15 contribute little to the present value cleanup costs of either program. At high discount rates, the permanent strategy is preferred because it provides a much shorter program,

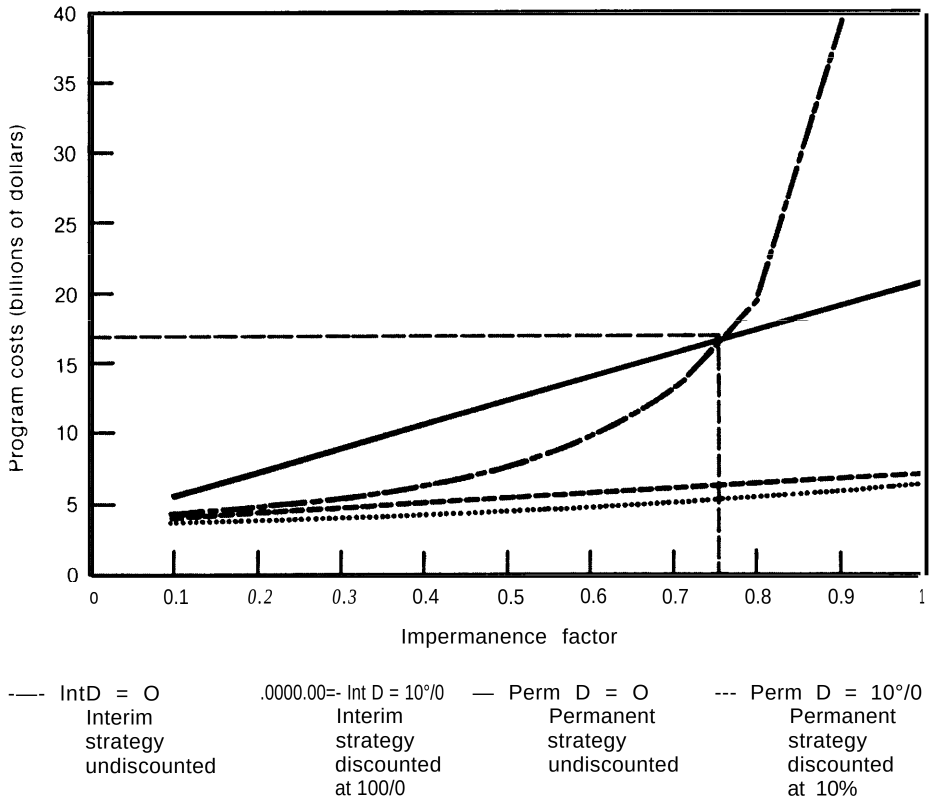
This application of discounting is limited to program evaluation, It helps make long-term strategic decisions. With this model, the strategic decisions made with discounted future costs generally are the same as those with undiscounted costs; preference for the interim strategy occurs only with certain and low future costs. No useful information for year-by-year financial planning is generated. Furthermore, to accurately identify the total costs of the cleanup program, other factors such as inflation and interest earned on cash balances, would have to be considered.

A Two-Part Strategy

What are the implications of these comparisons between interim versus permanent cleanup strategies for a variation of the permanent strategy with *initial responses at all NPL sites* (representing the two-part strategy described in chapters 1 and 2)?

Under the two-part strategy, technologies similar to those defined as interim technologies would be used for lower cost initial responses than those considered in the basic permanent strategy, Initial responses are not designed to be effective for long periods. The purpose of this cheaper, more limited response is to prevent sites from getting worse, and to control near-term releases of hazardous substances into the environment and, hence, exposures to them. Low-cost initial responses are one part of interim, impermanent approaches now be-

Figure 3-7.—Program Costs v. Impermanence
Undiscounted and discounted costs (Scenario 1ECO)



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ing described as cleanups. Low-cost initial responses could include pumping to contain plumes of contamination in aquifers, covers to keep out water, excavation and *temporary* storage of wastes and contaminated soil above ground (greatly reducing the use of below ground barriers), and environmental monitoring. In contrast to the current immediate removals, more money would be spent and removal of wastes to operating land disposal sites would be avoided.

A strategy of low-cost initial responses would achieve rapid risk reduction at many sites, thereby responding in an equitable manner to public demands for protection and visible progress. OTA's modeling, however, suggests that the costs of initial responses should be low (about 10 percent of permanent cleanup costs), and that they should be followed not by other impermanent responses, but rather by a permanently effective response. In this strategy the conservative assumption is made that 90 percent of all sites will need a permanent cleanup; that is, 10 percent of the initial responses will subsequently be found to be sufficient.

In this variation of the permanent strategy the costs of initial responses are: $1 million per site for surface response and $3 million per site to initially respond to groundwater contamination, Additionally, to examine the effect of many more sites, after all sites are discovered, 10,546 sites are to be cleaned and a higher budget is allocated. (Table 3-4 defines Scenario

1USG.) This variation was compared with the interim cleanup strategy under the same scenario.

The results are illustrated in figures 3-8a and 3-8b. They show that at an assumed impermanence factor of 0.9, the total program cost of the two-part strategy is about $310 billion. At an impermanence factor of about 0.73 in the interim strategy, the two strategies have the same program cost ($310 billion).

The two-part strategy is preferable to the interim strategy on the grounds of program duration, except for impermanence factors under about 0.25. If the impermanence of the interim responses is greater than 0.73, then the two-part strategy is preferred both in terms of total cost and program duration. When total program costs are the same for both strategies, the interim strategy results in an unacceptably long program (longer than 100 years).

Strategy decisions between the two-part strategy and the interim strategy are interestingly altered if high discount rates are used. With very high discount rates, the present value of program cleanup costs under either strategy become insensitive to the impermanence of the cleanup response. The costs incurred in the earliest years of the program determine the (present value) program cost. However, since initial actions are less costly than interim actions, with high *discount rates* the two-part strategy will result in lower discounted program costs, in addition to shorter programs, than the interim cleanup strategy. If there is sufficient justification for a high discount rate, then the two-part strategy with low-cost initial responses is preferable over all levels of impermanence.

In summary, the two-part strategy used initial (and emergency] responses as a first priority for allocating program resources, with remaining funds spent on permanent cleanups at sites that have been "isolated, " "decontrolled," or "stabilized." Exactly how funds would be allocated (the order of actions and cleanups) under this third strategy considering budget, qualified personnel, and technology constraints is an extremely difficult problem. Its solution depends on the resolution of the cleanup goals issue (see chapter 4) and a systematic approach to the problem that illuminates trade-offs.

CONCLUSIONS: PROGRAM PLANNING UNDER UNCERTAINTY

The results of the simulation exercise indicate that cleanup costs and program duration show a high degree of sensitivity to a number of uncertain factors. The potential effects of planning without considering these uncertainties also can be derived from the simulation findings. The probability of adverse effects of uncertainties could be limited in a carefully planned program, Table 3-7 presents the sources of uncertainties in the Superfund program as identified by OTA, the dangers posed by planning without considering them, and offers options to mitigate their adverse effects.

Effectiveness and the Future Cost of Cleanups

A primary element of uncertainty is *the* effectiveness of the cleanup responses and their future costs. OTA's findings indicate that *it is desirable to develop, demonstrate, and use permanent cleanups if the effectiveness of the interim cleanup and its future costs are uncertain. The interim cleanup strategy is preferred only if future costs are known to be small,* This is because the interim strategy results in an extremely long program (despite an advantage in total cleanup cost) for a wide range of interim

Figure 3-8a.—Program Length v. Impermanence Factor
Scenario 1USG

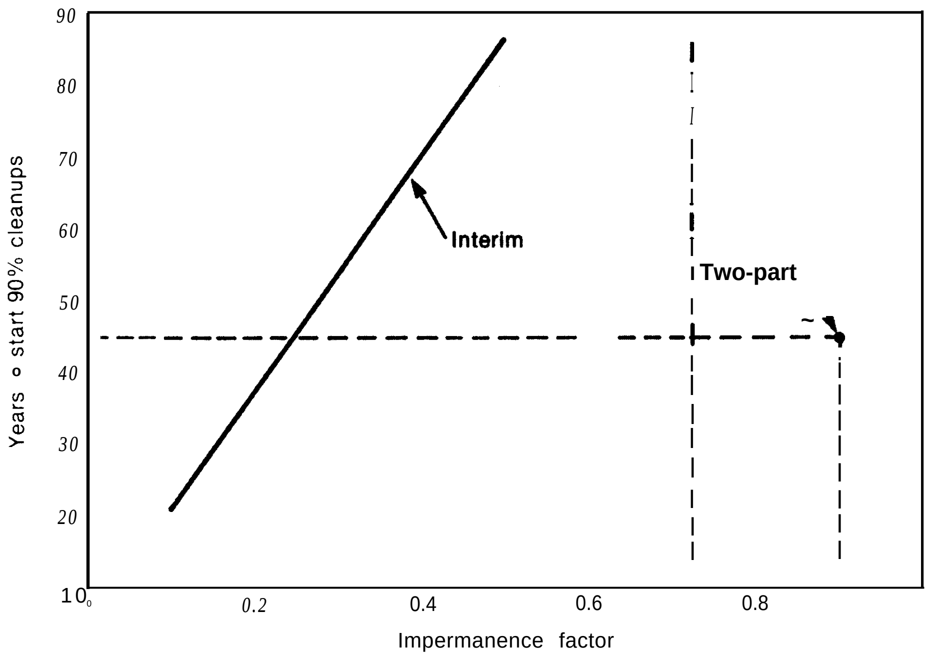

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Figure 3-8b.—Program Cost v. Impermanence Factor
Scenario 1USG

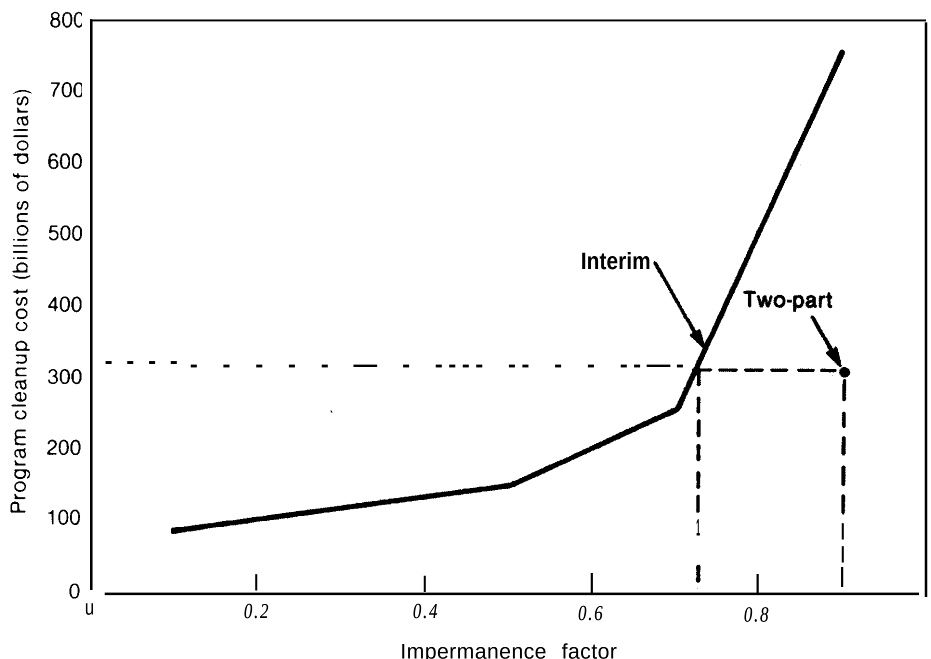

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Table 3-7.—Program Planning With Uncertainty

Dangers of planning without consideration of uncertainty	Options to hedqe against adverse effects
Effectiveness and future cost of cleanups: Inadequate funds and program infrastructure; • Cleanup delays . Increasing risks and cleanup costs Inefficient resource expenditures and cleanup choices: • Cleanup is not cost effective in the long term • Risks are aggravated rather than mitigated Loss of public confidence	• Incorporate future costs and cleanup effectiveness in cleanup strategy decisions • Limit costly impermanent cleanups • Develop long-term strategic plan for developing and using permanent cleanups
Number of sites requiring response: Inadequate funds and program infrastructure; • Cleanup delays . Increasing risks and cleanup costs Inefficient resource allocation: • Worst sites are not addressed —Risks and cleanup costs increase —Cleanup delays • Less hazardous sites are "over-cleaned" Loss of public confidence	• Consider all likely sources of sites; and potential for sites to enter program over long term • Develop long-term strategic plan based on revised estimates
Health ***and environmental effects:*** Inefficient resource allocation: • Worst sites are not addressed —Risks and cleanup costs increase —Cleanup delays • Less hazardous sites are ''over-cleaned" . Ineffective technologies continue to be used Loss of public confidence	Ž "Recontrol" responses at maximum number of sites . Resolve cleanup goals sequentially as improved information is available • Develop detailed strategic plan for long-term permanent cleanups
Non-Federal money: Inadequate funds and program infrastructure: • Cleanup delays • Increasing risks and cleanup costs Inefficient resource expenditures and cleanup choices • Cleanup is not cost effective in long term • Risks are aggravated rather than mitigated	• Use conservative estimates; refine estimates with experience
Discount rate: Inadequate funds: • Cleanup delays . Increasing risks and cleanup costs Inefficient resource expenditures and cleanup choices: Ž Cost effective responses not chosen . Risks are transferred,	• Exclude discount rate or use conservative discount rate; test sensitivity of cleanup strategy decisions to rates

SOURCE Off Ice of Technology Assessment

cleanup future costs. *A mistake in estimating future costs of interim cleanups carries the penalty of a drastic, unanticipated, lengthening of the program—and of a period of perhaps high risk–under the interim strategy.* For higher levels of future cost, the interim strategy results in both unacceptably high cleanup costs and program duration.

A program designed without consideration of cleanup response effectiveness and future costs is likely to result in a lack of money and inadequate program infrastructure. Even if more money is expeditiously provided, it is unlikely that the program infrastructure, or institutional delivery system, will be able to grow rapidly enough for timely responses. Indeed, a contributing factor to the slow startup of the 1980 program was simply the time required for organization and staffing. Further delays in the cleanup program may result in site deterioration and increasing risks. In turn, the costs of cleanup may escalate, impose greater financial burdens and delays; a crisis situation could ensue, In EPA's words, the program could be "overwhelmed. " In addition, *delays in cleanup and the use of ineffective cleanups may contribute to loss of public confidence.*

To deal with uncertainty about cleanup effectiveness and future costs, more realistic estimates can be used. For instance, *life-time* or *life-cycle* O&M costs could be included in cleanup cost estimates. The implications of incorporating realistic O&M costs can be significant, EPA has estimated average annual O&M costs at $400,000 per site, The average Federal cleanup cost per site, less the first year O&M, is about $7.5 million, This is comparable to the average cleanup costs used in the model which shows that if O&M costs are the only future costs of interim cleanup, and are incurred over only 5 years, then the corresponding impermanence factor is about 0.27. Thus, the inclusion of realistic O&M costs can reduce the margin for error.

Number of Sites

The number of sites that will ultimately require cleanup is another source of uncertainty which, if not adequately taken into account, could seriously impact the cleanup program. Insufficient money and an underdeveloped program infrastructure could result from overly optimistic (under) estimates of the number of sites to clean, The program grows too slowly for effective response and further delays result in site deterioration and increasing risks, increasing costs, further delays, and loss of public confidence.

Health and Environment Effects

Although health and environmental issues could not be incorporated into OTA's simple model, high uncertainties of their effects exist and their importance is felt in making tradeoffs, *If health and environmental effects are not better understood, and cleanup goals better defined, any program will potentially misallocate resources*. Without effective cleanup goals it is difficult to judge the effectiveness of cleanups, A rush to "cleanup" sites by, for example, mandating cleanup schedules, before goals are established could result in too many initial resources being devoted to: 1) the use of ineffective technologies; and 2) the less hazardous sites, depriving worse sites of attention.

One reliable way to plan with uncertainties in a dynamic system is to resolve the cleanup goal issue sequentially, incorporating new information as it becomes available, while taking more limited initial responses, and "recontroling" a maximum number of sites. At the same time, other initiatives should focus on planning for more extensive, permanent cleanups that will be needed at some sites, and which can be accomplished gradually.

Non-Federal Money

How much of cleanup costs will be provided by potentially responsible parties (PRPs), income from cost recovery, and States' shares? EPA estimates it will recover 47 percent for removals and 30 percent for remedial actions (see table 3-1).

The limited experiences of the program suggest that lower contributions will be received. As of September 30, 1984, cost recoveries have totaled $6.6 million, less than 1 percent of total obligations and disbursements toward hazardous substance response.[28] One cause of these high estimates is the assumption that rates of recovery will be comparable to those for early removals conducted under the Clean Water Act.

Direct cleanup actions by responsible parties are projected by EPA at 40 to 60 percent, Similarly, estimates from GAO range from 29 to 44 percent for RP lead activities (see table 3-1). The uncertainty of both these estimates may be heightened by the much larger numbers of sites and sums of money that could be involved. Additionally, it might be expected that it will become more difficult to identify some responsible parties as the program progresses and older, abandoned sites are identified, While many sites in the larger estimate maybe smaller, industrial surface impoundments, which may have associated with them lower remedial costs and fewer (often single), identifiable responsible parties, others may be large munici-

[28] U.S. Environmental protection Agency, "Hazardous Substance Response Trust Fund Receipts, Obligations, and Disbursements, CERCLA Sections 301(a)(l)(B) and (D)" [Washington, DC: Office of Solid Waste and Emergency Response, December 1984).

pal landfills. This broader, more costly aspect of the program may stress the States' willingness to provide their matching shares of construction costs.

Discount Rate

The differences between present and future values of cleanup expenditures and risks result from uncertainty over future values of money, inflation, and risks. Cleanup costs and risks may occur over a period of decades. Discounting is used in program evaluations and planning to adjust the costs and risks to present value. The discount rate, an expression of the time value of money, should reflect how society values current versus future consumption.

To illustrate how costs and risks might be valued differently over time, consider a decision-maker faced with the choice of a program that costs $5 billion now and $5 billion over the next 20 years and a program that costs $10 billion now. The choice might be simplified if it could be shown that the $10 billion program reduces risk more over the next 20 years and if a reliable dollar number could be calculated for the risk reduction. However, in reality, the difference in risk reduction associated with program options is rarely simple.

Controversy arises over the choice of discount rates for public investrnents.[29] One school of thought holds that society should have a longer planning horizon than individuals, which means that public discount rates should be lower than private rates, Furthermore, since future generations have no way to express their preferences, an unimaginative society may err on the side of too high discount rates, from the point of view of their descendants. Many would argue that this is happening now.

OTA makes no attempt here to resolve these issues. However, discounting often has utility, and the selection will influence the allocation of resources, the level of social welfare, and cleanup strategy. *If the discount rate is too high the Superfund program may be underplanned.*

Means to Address Uncertainties

The potential risks arising from uncertainty can be mitigated in several ways. Clearly, resolving the uncertainties would be the most efficient approach, Resources can be devoted to learning how many sites will require cleanup, understanding health and environmental risks, developing cleanup goals, and deciding on a realistic, achievable level of non-Federal contributions. However, *the cleanup program can not wait for total and perfect knowledge.* Rather, the program plan should be sequentially refined as new information is available.

The effectiveness of currently used cleanup technologies and the extreme sensitivity of program duration and cost to these uncertainties suggest that efforts are needed to develop permanent cleanup technologies. *Limited initial responses in the near-term make economic and environmental sense only if they are part of a long-term, flexible strategic plan whose goal is permanent cleanup.* Otherwise, public confidence will not be obtained.

There are intrinsic conflicts between maximizing the number of limited initial responses, and their effectiveness over time, and keeping their costs low to save enough money for expensive permanent cleanups. In addition, there will be competition for money and people for research, demonstration, and use of permanent technologies, and enforcement. Furthermore, a method to allocate and schedule cleanups efficiently must be part of a long-term strategic plan,

[29] For private sector investments, the discount rate is applied to known investment costs and anticipated benefits, both of which can usually be calculated easily in dollars. The appropriate discount rate is usually the corporate internal rate of return on capital or the rate of return on alternative investment opportunities.

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APPENDIX A

This appendix provides detailed information on the mathematical formulations and assumptions used in OTA's model discussed in chapter 3.

Undiscounted Program Cost Definitions of Cleanup Strategies

If costs are not discounted, total program costs can be derived without the use of simulation. Three strategies are defined and discussed in terms of costs and cost comparisons.

Interim Cleanup Strategy

The total undiscounted program costs adjusted for future costs, TC_I, under the interim cleanup strategy can be expressed mathematically as:

$$TC_I = C_IX + iC_IX + i^2C_IX + i^3C_IX + i^4C_IX + \ldots \quad (1,1)$$

where:

C_I = average near-term cost of an interim action.
X = number of sites to clean up.
i = average system impermanence factor of interim actions.

In equation (1.1), the first term is total near-term costs of interim actions. The remaining terms, which constitute a geometric series, represent total future costs of all future actions. (It should be noted that if O&M costs are included in i, they may be understated if $i < 1$, since the terms decrease,) For all $i < 1$, this series converges, so that:

$$TC_I = C_IX/(1 - i) \quad (1.2)$$

Thus, the average adjusted cost per site under the interim strategy is:

$$Avg(TC_I) = C_I/(1-i) \quad (1.3)$$

Equation (1.2) elucidates the use of the impermanence factor in the interim strategy. Rearranging terms reveals:

$$TC_I = C_IX + iTC_I \quad (1.3a)$$

The total cost of the interim strategy is composed of the total near-term cost, C_IX, plus total future costs, iTC_I. In the model, however, equation (1,2) was only used as a tool for terminating scenarios that exceeded computer memory. Actual cost calculations were made on the basis of equation (1.1). Clearly, no scenario with a system impermanence factor equal to or greater than 1 was run since, on the basis of either equations (1.1) or (1.2), total cost will be infinite.

Basic Permanent Cleanup Strategy

The total undiscounted program costs adjusted for future costs, TC_P, under the permanent cleanup strategy can be expressed mathematically as:

$$TC_P = C_IYX + C_PiYX + C_P(1 - Y)X \quad (1.4)$$

where:

C_P = average cost of a permanent action
Y = percent of all sites addressed by an initial action during the first 15 years of the program. This percentage will be dependent on funding availability during the 15 years.

The first term in equation (1.4) represents near-term costs of the impermanent interim actions taken in the first 15 years. In the basic permanent cleanup strategy, the interim actions are the same as the interim actions under the interim strategy: the technologies are the same, the costs are the same, and the impermanence factor is the same. The second term is the future costs of initial actions relating to the need for second but permanent actions. This term may misestimate total costs since permanent cleanup costs after an initial action may be more or less than costs of permanent cleanups at sites that have had no response, The last term is the costs of permanent cleanup at sites that have no response. The average cost per site under the permanent cleanup strategy is:

$$Avg(TC_P) = C_IY + C_P(iY + \quad (1.5]$$

Two-Part Strategy

The two-part strategy is a variation of the permanent strategy and differs from the basic permanent strategy in that the initial responses are not necessarily the same as those of the interim strategy, The unit cost is less for an initial response than for an interim response. Therefore, the impermanence factors may be different for initial responses and interim responses. The total cost of the variation of the permanent strategy, TC_{PV}, may be expressed as:

$$TC_{PV} = C_{IV}YX + C_Pi_VYX + C_P(1 - Y)X \quad (1.6)$$

where:

C_{IV} = average near-term cost of an initial action.
i_V = impermanence factor for initial actions.

New Sites

In all of the strategies, new sites are discovered during the first *15* years of the program. These sites may be responded to in the following year. Slight deviations from the above cost formulae occur as a result of sites entering the system in the 15th year. In the basic permanent strategy and the two-part strategy, these sites only receive permanent cleanups.

Cost Comparisons of the Interim and Basic Permanent Strategies

Since the interim actions considered in the interim and basic permanent strategies are identical, equations *(1. 1)* and *(1.4)* can be equated and solved for in terms of i. The impermanence factor at which either total program costs or average program costs are equal under either strategy, i*, is called the critical impermanence and is expressed as:

$$i^* = 1 - C_I/C_P \qquad (1.7)$$

At this impermanence factor, we are indifferent to the cleanup strategies, on a cost basis. For all i < i*, the interim strategy is preferred if only cost is considered and duration [discussed below) is ignored. For all i > i*, the permanent strategy is unambiguously preferred.

Cost Comparisons of the Interim and Two-Part Permanent Strategies

The difference between the interim actions of the interim strategy and the initial actions of the two-part permanent strategy demand a different cost comparison method than that stated above. Given equations (1. *1)* and (1.6), a total cost for the two-part strategy can be based on a specific value for i_v. The impermanence factor for the interim strategy, i, can then be determined and results in the same total cost. If the impermanence factor for interim actions is above this level, then the two-part permanent strategy is unambiguously preferred.

Program Duration With Uncertain Technology Effectiveness

While undiscounted program costs can be derived mathematically, simulation must be employed to determine program duration under each strategy and to determine the effects of discounting, which is time dependent, on cleanup strategy decisions. A simulation model, programmed using LOTUS **1-2-3,** was developed to mimic cleanup actions, the impermanence of those actions, and additional actions resulting from impermanence, over time, The following discussions are focused on the interim and basic permanent strategies. While the discussions are related to the two-part permanent strategy, modifications in analysis would have to be made.

Impermanence Factor

In the model, two impermanence factors were used: i(sc), the impermanence factor for interim surface actions, and i(gw), the impermanence factor for interim groundwater actions. This breakdown is consistent with previous calculations since these two cleanup types are assumed to be independent of one another. The independence assumption may compound the conservative estimate of the percent of sites requiring groundwater response (20 percent) since it does not permit sites with surface contamination to deteriorate in a way that causes groundwater contamination. In fact, surface contamination often leads to ground water contamination. If, however, the impermanence factor for surface contaminated sites is high, it may capture the future costs associated with deterioration. Total program costs under the interim strategy can be expressed as:

$$TC_I = C_{Isc}(1 - Y_{gw})X/(1 - i(sc)) + C_{Igw}(Y_{gw}X)/(1 - i(gw)) \qquad (3.1)$$

where:

C_{Isc} = average near-term cost of an interim surface action.
C_{Igw} = average near-term cost of an interim groundwater action.
Y_{gw} = percentage of all sites requiring groundwater response.

Similarly, total program costs under the permanent strategy are:

$$TC_P = C_{Isc}Y(1-Y_{gw})X + C_{Igw}YY_{gw}X + C_{Psc}(1-Y_{gw})(i(sc)Y + (1-Y))X + C_{Pgw}Y_{gw}(i(gw)Y + (1-Y))X \qquad (3.2)$$

where:

C_{Psc} = average cost of a permanent surface action.
C_{Pgw} = average cost of a permanent groundwater action.

Separability of costs relating to surface actions and groundwater actions permits the derivation of individual critical impermanence factors, i*(sc) and i *(gw), the impermanence factors where costs associated with surface actions and groundwater actions, respectively, are equal under either strategy. These are:

$$i^*(sc) = 1 - C_{Isc}/C_{Psc} \qquad (3.3a)$$

$$i^*(gw) = 1 - C_{Igw}/C_{Pgw} \qquad (3.3b)$$

The composite or average impermanence factor can be determined from equations (3.3a and b). For example, the average critical impermanence factor, i*, can also be expressed as:

$$i^* = i^*(sc)(1 - Y_{gw}) + i^*(gw)Y_{gw} \qquad (3.4)$$

The simulation was verified using equations (3.3a,b, and 3.4). These results are discussed and were also used to ascertain program durations when the undiscounted program costs of both strategies were equal.

Base Case Simulation

To model the system, various system definitions and assumptions about model parameters are required. These model definitions (presented in table 3-3) represent conservative estimates of their real world analogs.

To calibrate the model, a base case is generated where the uncertain estimates are defined to closely match current real world estimates. Although it is incorrect to use the term interim cleanup strategy if the impermanence factor is zero, simulation of this case provides a base case and comparison with current EPA estimates of program costs and length. The zero impermanence assumption appears to be consistent with EPA's exclusion of future costs from cost estimates for currently used technologies. Budget options A and C were the lowest budgets that gave base case program durations similar to EPA estimates (see table A-l).

Uncertain Assumptions and Model Sensitivity

To determine program durations under each strategy, it is necessary to make assumptions about the impermanence of interim actions, the number of sites that will require cleanup, the annual budget devoted to cleanup actions, how the budget is allocated among sites, when future costs are incurred, average costs of permanent technologies, and discount rates. The performance of each strategy was tested under different scenarios defined in table 3-4. The goal of this exercise is to clarify a cleanup strategy toward which the Superfund program could move if there is uncertainty about the permanence of currently used technologies. If the model is overly sensitive to some assumptions (namely, when the future costs occur, the annual budget, the costs of permanent technologies and discount rates), then few if any general unqualified statements can be made about cleanup strategy decisions under uncertainty, If, however, the results remain generally the same while each element of uncertainty is varied, then the model can provide meaningful conclusions about cleanup strategy decisionmaking. First, the methods of incorporating these assumptions into the model are discussed; the sensitivity of the model to these assumptions follows.

Assumptions About Timing

While the assumptions about how long it takes to perform an interim cleanup are founded in experiential data, little data exists on which to base assumptions about how long after an impermanent action future costs are incurred, That future costs do, indeed, result from impermanent actions has not been recognized much less quantified. The sensitivity of the model to assumptions about the timing of future costs was tested, Three options were used: 1) early occurrences (every 5 years), 2) late occurrences (every 30 years), and 3) occurrences uniform over 30 years. In the early option, there

Table A-1 .—Comparison of Simulation Base Case With Current Estimates[a]

	EPA (1984)	EPA (1983)	Base case
Total costs (billion)	$7.6 -$22.7	$10.3 -$20.6	$14.7
Projected time to clean sites	NA	14 years for 1,800 sites	16-17 years[b]
Number of sites	1,500-2,500	1,400-2,200	2,046
Total average cleanup cost per site	$8.84'	$6 M $12 M including groundwater response	$6 M $12 M including groundwater response
Percent of sites requiring groundwater response	NA	23-560/o	20%
Average length of response	NA	3 years[d]	3 years 6 years including groundwater response

a F. sources and additional information see table 3-1 of this chapter
b Range corresponds to Budget Options A and C
c Does not include initial remedial measures
d U s Environmental Protection Agency, "CERCLA 301(a)(l)(c) Study, " draft, December 1984

SOURCE As noted

would be rapid response and early information on the level of impermanence. The late option corresponds to the 30-year period required under RCRA for post-closure care of disposal facilities. The uniform distribution reflects that sites and cleanups will vary.

Some Examples of Timing

The mathematical formulation follows, but several simple, nonmathematical examples are given first.

(I) Assume the interim strategy, surface cleanups only, with an impermanence factor of 0.5, and the 5-year timing option. Then, of every 100 primary cleanups started in year 1 of the program, there will be 50 secondary cleanups at the same cost as the primaries (or 100 secondaries at half the cost of the primaries) started in year 9 of the program, and 25 tertiaries at the same cost as the primaries (or 100 tertiaries at one-quarter the cost of the primaries) started in year 17 of the program. The secondaries are started in the ninth year of the program, rather than the sixth, because they are started 5 years after the completion of the primaries, and it takes 3 years to perform a surface cleanup.

(II) Assume the interim strategy, surface cleanups only, impermanence factor of 0.5, and the uniform timing option. Then, 120 primary cleanups started in year 1 of the program will be followed by three sets consisting of: a) 10; b) 20; and c) 30 secondaries at the same cost as the primaries (or: a) 20; b) 40; c) 60 secondaries at half the cost of the primaries) which will be started in years 9, 19, and 34 of the program. That is, the "uniform" distribution is not continuously uniform, but is clumped in three bunches. (This choice was made for ease of computing; a more accurate representation of a discrete uniform distribution using more and smaller intervals could have been used with a faster computer.) Note also, that tertiary and higher order actions following early secondary cleanups overlap with later secondary cleanups of the same primary set.

(III) Assume the permanent strategy, with surface cleanups only, and impermanence factor of 0.5 and the uniform timing option. This means that, if 120 initial responses are started in year 1 of the program, 10 require a future action in year 9, 20 in year 19, and 30 in year 34; these 60 sites are slated for permanent cleanup. The sites that require additional action in year 9 cannot be addressed until year 15 or later; they go into a pool of sites that will receive permanent cleanup in the future.

How the Model Handles Timing, Mathematically

Future costs are incorporated into the model by pooling future action requirements. Let $F_{sc}(t)$ and $F_{gw}(t)$ denote the **costs** of future actions that become necessary at time t due to previous interim surface and groundwater actions, respectively. Let $X_{sc}(t)$ and $X_{gw}(t)$ indicate the number of interim surface and groundwater actions started in year t. For future costs incurred on the early schedule, the undiscounted costs of actions that enter the pool for future action in year t are related to previous actions so that:

$$F_{sc}(t) = i(sc)C_{Isc}X_{sc}(t-8) \quad \textbf{(4.1a)}$$

$$F_{gw}(t) = i(gw)C_{Igw}X_{gw}(t-11) \quad (4,11))$$

The 8-year lag in future costs for interim surface actions reflects the 3 years required to complete the action and the 5 years after that before which future actions are required. Similarly the 11-year lag for interim ground water actions includes 6 years to complete the action.

If the future actions are required after 30 years, the lags become 33 years for interim surface response and 36 years for interim groundwater response, so that:

$$F_{sc}(t) = i(sc)C_{Isc}X_{sc}(t-33) \quad (4.2a)$$

$$F_{gw}(t) = i(gw)C_{Igw}X_{gw}(t-36) \quad (4.2b)$$

For future actions that are required on a 30-year uniform schedule, the time distribution is represented discretely in the model, with costs incurred 5, 15, and 30 years after completion of the interim actions. The undiscounted costs of actions required in year t are related to previous actions as:

$$F_{sc}(t) = 1/6[i(sc)C_{Isc}X_{sc}(t-8)] + 2/6[i(sc)C_{Isc}X_{sc}(t)-18)] + 3/6[i(sc)C_{Isc}X_{sc}(t-33)] \quad (4.3a)$$

$$F_{gw}(t) = 1/6[i(gw)C_{Igw}X_{gw}(t-11)] + 2/6[i(gw)C_{Igw}X_{gw}(t)-21)] + 3/6[i(gw)C_{Igw}X_{gw}(t-36)] \quad (4.3b)$$

As before, the lags of 3 and 6 years reflect completion time for interim surface and groundwater response, respectively,

In all of the cases above, the future costs of an interim action are a function of the number of actions taken, the costs of those actions, and their impermanence.

In the permanent strategy, impermanence of the initial actions results in permanent response. Let $P_{sc}(t)$ and $P_{gw}(t)$ denote the **number of permanent** actions taken in year t due to previous impermanent actions, The future costs associated with the initial actions can be represented mathematically' in a way similar to equations (4.1a-4.3b), depending on the time distribution of future actions. For example, if future actions are required under the early time distribution, they are:

$$P_{sc}(t) = i(sc)C_{Psc}X_{sc}(t-8 \qquad (4.4a)$$

$$P_{gw}(t) = i(gw)C_{Pgw}X_{gw}(t-11 \qquad (4.4b)$$

In this case, costs resulting from impermanent actions are a function of the number of impermanent actions taken, the impermanence of those actions, and the costs of permanent cleanup.

Comments on Timing

The assumptions about the time distribution of future actions may directly determine the program duration, although it is typically these assumptions together with budget assumptions that do so. If the budget is large enough, and grows quickly enough, then the bulk of the cleanup efforts can be achieved earlier in the program. However, the results of impermanent actions linger. For instance, if there were no budget constraints, under the permanent strategy all initial responses would be taken in the first year. The latest future groundwater actions that would result from these impermanent actions would be dealt with in the 37th year (6 years to complete the action and 30 years until additional action is required), The shortest program attained in the modeling effort for the permanent strategy was 26 years. This reflected the last initial groundwater cleanups starting in the 15th year. Six years is required to complete the initial response, then future actions can be started 5 years later, under the early time distribution of future action occurrence. Of course, with expensive enough permanent cleanups, high enough impermanence factors, and/or a low enough budget, the program would be longer, as there would not be enough money to do all permanent cleanups in the year they came due.

Any of the time lags before future actions are taken may be lengthened because of the budget constraints. Because the model incorporates no measure of risk, future actions may be deferred without penalty, *Therefore, in this model, no distinction is made in allocating the budget between sites requiring first time* ***response and sites*** *requiring additional response.* (The only exception is for permanent responses under the permanent strategy during the first 15 years; they are not permitted,)

Budget Allocation

Each annual budget is allocated so that the fund is distributed in a deterministic way among surface and groundwater responses, primary and follow-on responses, Consider first the interim strategy, If $S_{sc}(t)$ indicates the number of sites that have never been addressed requiring surface response in year t, and $S_{gw}(t)$ is similarly defined for sites requiring groundwater response, then an allocation percentage, Y_t, is defined for an annual budget in year t, B(t), as follows:

$$Y(t) = B(t)/[C_{Isc}S_{sc}(t) + C_{Igw}S_{gw}(t) + F_{sc}(t) + F_{gw}(t)] \qquad (5.1)$$

The percentage is similar during the first 15 years of the permanent strategy except there are no terms for future costs. Instead, the future costs enter the model when permanent cleanups are pursued, after the 15th year. The percentage then becomes:

$$Y(t) = B(t)/[C_{Psc}S_{sc}(t) + C_{Pgw}S_{gw}(t) + P_{sc}(t) + P_{gw}(t)] \qquad (5.2)$$

The effect of this allocation is response to sites with surface and groundwater contamination in the same proportion as their occurrence. If the impermanence factors for interim and initial actions for surface and groundwater contamination are the same, this proportion is maintained through the simulation; that is, the initial 80 percent surface to 20 percent groundwater occurrence assumed in the model stays constant as the program runs. (Note that groundwater responses are more expensive than surface response by a factor of 3 in most simulations; therefore if the ratio of occurrence is 80:20, the budget is split as 0.57 :0.43, the ratio of cost.) If, however, the impermanence factors are different the proportion will change. For example, if the groundwater responses have higher impermanence, more attention and money will be devoted to groundwater response as the program progresses.

One outcome of this allocation method is that no preference is given to primary actions under either strategy. It is possible, therefore, that with a low enough budget and high enough impermanence factor, nearly all funds could be devoted to secondary and higher order interim actions in the interim strategy and secondary but permanent actions in the permanent strategy. This is particularly striking if future actions are required on the early time distribution schedule, While the real-world implications of this are unappealing, i.e., sites are not addressed and deteriorate, this poses few problems in terms of affecting the performance of the strategies in the simulation. The correct amount of money is spent and it is the length of time these expenditures continue that determines program length,

Measuring Program Duration

To evaluate the strategies in terms of program length and examine the effects of different time distributions of future cost occurrences, a method of measuring program duration was required. Program duration could be measured in terms of the last year where expenditures are made for an action. Since responses extend over time, this way of measuring duration would shorten program length by at most 10 years, the time required to complete the longest response—the permanent groundwater cleanup.

By definition the interim cleanup strategy for i < 1 represents a decay process, meaning that fewer and fewer interim actions are taken over time. It would be misleading to measure program duration by the time needed to initiate the final single action (or fraction, thereof, since real variables were used). By the same token, it would be equally misleading to only consider the time required to initiate all first interim actions since these might constitute only a very small fraction of the total program under the interim strategy.

To resolve this dilemma, program progress was measured in terms of the year at which different percentages of all expected cleanups were undertaken. The percentiles are 30, 50, 70, 90, 95, and 100 percent. Assuming that the model did delineate between primary and future actions, a simple interpretation of progress percentiles can be given. For instance, under the interim cleanup strategy, if i(sc) = i(gw) = 0.7, the 30 percent program progress might mean (depending on the timing of future actions) that at most all first interim cleanups were completed, and no future actions had started. For i(sc) = i(gw) > 0.7, the 30 percent program progress mark would have to include additional future actions. In general, the minimum program progress level required to cleanup all sites with an interim action exactly once, under the interim strategy is:

$$X(\%) = 100(1 - i) \qquad (6.1)$$

The inverse relationship may bias strategy decisions toward the interim strategy for low impermance factors if low program progress percentiles are used to measure duration. For example, if a 30 percent program progress level is used for i = 0.1 under the interim strategy, this represents no more than the first cleanup of only one-third of the sites. *For this reason, the* **90** *percent program progress level, which could represent first cleanup of all sites if the i* = 0.1 *(the lowest impermanence factor tested], was used to measure program progress.*

Model Sensitivity

Each strategy was simulated for impermanence factors where total costs were supposed to be equal for the two strategies. Varying budgets (options A, B, C, and D) were run to verify that cleanup actions were modeled properly and that correct program costs were generated, and to derive corresponding program durations. Results are given in table A-2. All program costs were equal at the critical impermanence factors, i*(sc) = 0.75 and i*(gw) = 0,8, thereby verifying this aspect of the model,

Despite the mathematical justification for measuring program duration in terms of the 90 percent program progress level, to arrive at a verifiable conclusion each strategy was compared in terms of program duration at all program progress levels. (See tables A-3a and A-3b for simulation results at different impermanence factor levels.) At the critical impermanence factors for permanent cost option 1, where program costs of the two strategies are equal, the interim strategy performs poorly in terms of program duration even at the 30 percent program progress level (refer to tables A-4a and A-4 b).

Table A-2.—Simulation of Cleanup Program Progress Ranges of Years in Which Required Cleanups are Initiated[a] Total Program Cost $63.6 Billion

	Selected percentages of sites					
	30%	50%	70%	90%	95%	100%
I. *Initial Budget = $1.6 B; i(sc) = 0.75; i(gw) = 0.8*						
Cleanup strategy:						
Interim	19-48	31-90	48-140+	84-140+	110-140 +	140 +
Permanent	12-19	16-47	22-65	26-79	26-82	27-85
II. *Initial Budget = $9.0 B; i(sc) = 0.75; i(gw) = 0.8*						
Cleanup strategy:						
Interim	14-37	25-75	42-140+	79-140+	104-140+	140 +
Permanent	7	14	19-40	24-53	25-56	26-59

[a]Range definitions
I Shortest programs correspond to scenario 1 EAF longest programs to scenario ILBF
II Shortest programs correspond to scenario 1 ECF longest programs to scenario 1 LDF

SOURCE Office of Technology Assessment

Table A-3a.—Trade-offs Between Program Cost and Program Progress: Scenarios 1-AF

Impermanence factors for impermanent surface actions (sc) and groundwater (gw) cleanups

Time distrib.	Program progress	i(sc) = i(gw) = 0.1 Interim	i(sc) = i(gw) = 0.1 Permanent	i(sc) = i(gw) = 0.3 Interim	i(sc) = i(gw) = 0.3 Permanent	i(sc) = i(gw) = 0.5 Interim	i(sc) = i(gw) = 0.5 Permanent	i(sc) = i(gw) = 0.6 Interim	i(sc) = i(gw) = 0.6 Permanent	i(sc) = i(gw) = 0.7 Interim	i(sc) = i(gw) = 0.7 Permanent	i(sc) = 0.75 i(gw) = 0.8 Interim	i(sc) = 0.75 i(gw) = 0.8 Permanent	i(sc) = i(gw) = 0.8 Interim	i(sc) = i(gw) = 0.8 Permanent	i(sc) = i(gw) = 0.9 Interim	i(sc) = i(gw) = 0.9 Permanent
Uniform (U):																	
	90%	17	21	49	33	83	41	113	43	>140	44	>140	44	>140	44	>140	45
	70%	16	15	17	18	45	21	56	21	82	22	109	23	132	24	>140	27
	50%	13	13	15	14	17	15	33	15	48	16	62	16	75	17	>140	18
	30%	11	10	12	11	14	12	15	12	17	12	31	12	39	12	81	13
Total program cost:		$16.4 B	$31.4 B	$21.0 B	$41.1 B	$29.5 B	$50.8 B	$36.8 B	$55.6 B	$49.1 B	$60.5 B	$63.8 B	$63.8 B	$73.7 B	$65.3 B	$147.3 B	$70.2 B
Early (E):																	
	90%	17	21	25	22	38	24	48	25	64	25	84	26	97	26	>140	26
	70%	16	15	17	18	24	20	28	21	38	22	48	22	55	22	105	23
	50%	13	13	15	14	17	15	20	15	25	16	31	16	34	17	64	17
	30%	11	10	12	11	14	12	15	12	17	12	19	12	22	12	37	13
Total program cost:		$16.4 B	$31.4 B	21.0 B	$41.1 B	$29.5 B	$50.8 B	$36.8 B	$55.6 B	$49.1 B	$60.5 B	$63.8 B	$63.8 B	$73.7 B	$65.3 B	$147.3 B	$70.2 B
Late (L):																	
	90%	17	21	51	44	111	46	>140	46	140	47	>140	47	>140	47	>140	47
	70%	16	15	17	18	49	21	78	35	112	39	>140	40	>140	40	>140	41
	50%	13	13	15	14	17	15	45	15	51	16	81	16	105	17	>140	18
	30%	11	10	12	11	14	12	15	12	17	12	44	12	48	12	111	13
Total program cost:		$16.4 B	$31.4 B	$21.0 B	$41.1 B	$29.5 B	$50.8 B	$36.8 B	$55.6 B	$49.1 B	$60.5 B	$63.8 B	$63.8 B	$73.7 B	$65.3 B	$147.3 B	$70.2 B

SOURCE: Office of Technology Assessment.

Table A-3b.—Trade-offs Between Program Cost and Program Progress: Scenarios 1-CF

Impermanence factors for impermanent surface actions (sc) and groundwater (gw) cleanups

Time distrib.	Program progress	i(sc) = i(gw) = 0.1 Interim	i(sc) = i(gw) = 0.1 Permanent	i(sc) = i(gw) = 0.3 Interim	i(sc) = i(gw) = 0.3 Permanent	i(sc) = i(gw) = 0.5 Interim	i(sc) = i(gw) = 0.5 Permanent	i(sc) = i(gw) = 0.6 Interim	i(sc) = i(gw) = 0.6 Permanent	i(sc) = i(gw) = 0.7 Interim	i(sc) = i(gw) = 0.7 Permanent	i(sc) = 0.75 i(gw) = 0.8 Interim	i(sc) = 0.75 i(gw) = 0.8 Permanent	i(sc) = i(gw) = 0.8 Interim	i(sc) = i(gw) = 0.8 Permanent	i(sc) = i(gw) = 0.9 Interim	i(sc) = i(gw) = 0.9 Permanent
Uniform (U):																	
	90%	16	16	45	35	79	38	108	39	>140	39	>140	40	>140	40	>140	41
	70%	12	12	16	14	39	17	52	20	78	22	105	23	127	23	>140	25
	50%	7	7	10	9	16	11	28	12	42	13	56	14	71	14	>140	15
	30%	3	3	5	4	8	5	11	6	15	6	25	7	35	7	76	7
Total program cost:		$16.4 B	$23.2 B	$21.0 B	$35.3 B	$29.5 B	$47.5 B	$36.8 B	$53.6 B	$49.1 B	$59.6 B	$63.8 B	$63.8 B	$73.7 B	$65.7 B	$147.3 B	$71.8 B
Early (E):																	
	90%	15	16	22	19	33	21	43	22	59	23	79	24	91	24	>140	25
	70%	11	12	14	14	19	17	24	18	33	19	42	19	49	20	100	21
	50%	7	7	10	9	13	11	15	12	20	13	25	14	30	14	59	15
	30%	3	3	5	4	8	5	10	6	12	6	14	7	17	7	32	7
Total program cost:		$16.4 B	$23.2 B	$21.0 B	$35.3 B	$29.5 B	$47.5 B	$36.8 B	$53.6 B	$49.1 B	$59.6 B	$63.8 B	$63.8 B	$73.7 B	$65.7 B	$147.3 B	$71.8 B
Late (L):																	
	90%	16	16	49	40	105	43	>140	44	140	44	>140	44	>140	45	>140	45
	70%	12	12	16	14	46	34	73	35	106	36	>140	36	>140	36	>140	37
	50%	7	7	11	9	16	11	38	12	49	13	75	14	100	14	>140	15
	30%	3	3	5	4	8	5	11	6	16	6	37	7	42	7	105	7
Total program cost:		$16.4 B	$23.2 B	$21.0 B	$35.3 B	$29.5 B	$47.5 B	$36.8 B	$53.6 B	$49.1 B	$59.6 B	$63.8 B	$63.8 B	$73.7 B	$65.7 B	$147.3 B	$71.8 B

SOURCE: Office of Technology Assessment

Table A-4a.—Summary of Simulation Results With Budget Options A and B[a] Program Duration Ranges for i = 0.1 to 0.9[b] (in years)

Time distribution option: Program progress	Permanent strategy cost range: $31.4	$70.2B[c]	Interim strategy cost range: $16.4	$147.3B[c]
Uniform (U):				
100%	51		101	140 +
95%	28	47	38	140 +
90%	21	45	17	140 +
70%	15	27	16	140 +
50%	13	18	13	140 +
30%	10	13	11	81
Early (E):				
100%	26	28	41	140 +
95%	21	27	22	140 +
90%	21	26	17	140+
70%	15	23	16	105
50%	13	17	13	64
30%	10	13	11	37
Late (L):				
100%	51		119	140 +
95%	42	48	47	140 +
90%	21	47	17	140 +
70%	15	41	16	140 +
50%	13	18	13	140 +
30%	10	13	11	111

[a]Permanent cleanup costs option 1 and new sites option F.
[b]Short programs correspond to budget option A and i = 0.1. Long programs correspond to budget option B and i = 0.9.
[c]Low cost corresponds to budget option A and i = 0.1. High cost corresponds to budget option B and i = 0.9.

SOURCE: Office of Technology Assessment.

Table A-4b.—Summary of Simulation Results With Budget Options C and D[a] Program Duration Ranges for i = 0.1 to 0.9[b] (in years)

Time distribution option: Program progress	Permanent strategy cost range: $23.2	$71.8B[c]	Interim strategy cost range: $16.4	$147.3B[c]
Uniform (U):				
100%	51		98	140 +
95%	29	45	35	140 +
90%	16	41	16	140 +
70%	12	25	12	140 +
50%	7	15	7	140 +
30%	3	7	3	76
Early (E):				
100%	26	27	39	140 +
95%	17	26	16	140 +
90%	16	25	15	140 +
70%	12	21	11	100
50%	7	15	7	59
30%	3	7	3	32
Late (L):				
100%	51		115	140 +
95%	38	47	41	140 +
90%	16	45	16	140 +
70%	12	37	12	140 +
50%	7	15	7	140 +
30%	3	7	3	105

[a]Permanent cleanup costs option 2 and new sites option F.
[b]Short programs correspond to budget option C and i = 0.1. Long programs correspond to budget option D and i = 0.9.
[c]Low cost corresponds to budget option C and i = 0.1. High cost corresponds to budget option D and i = 0.9.

SOURCE: Office of Technology Assessment.

Since under either strategy, for i < i*, the interim strategy is preferred on the basis of cost. But program durations under the interim strategy so greatly exceed those of the permanent strategy at the critical impermanence factor that trade-offs between program cost and duration are expected. Therefore, the hypothesis for cleanup strategy decisionmaking based on two evaluation criteria at this point is: *Regardless of when future costs occur and how we choose to measure program progress:*

1. The permanent strategy is preferred unequivocally for i > i* because it is both cheaper and shorter.
2. For i < i*, there are trade-offs between program cost and length.
3. At some level of impermanence, the interim strategy is preferred both in terms of program cost and duration.

To be sure the method of measuring program progress or assumptions about the time distribution of future costs do not disprove this hypothesis, sensitivity analysis is performed.

All program progress levels for each strategy were calculated while varying values of i = (0.1, 0.3, 0.5, 0.6, 0.7, 0.8, and 0.9). To properly ascertain the shortest and longest program duration, the time distributions of future costs and budgets were also varied. The shortest program under each strategy is achieved for the high growth rate budget options, A and C, and for the early future cost time distribution. The longest program under each strategy occurred for the low growth budget option B and D and for the late future cost time distribution. This information is given in tables A-5 and A-6.

Examination of these tables shows that the hypothesis is supported, since parts 1 and 3 are true, and 2 is intuitive. Regardless of when future costs occur and our measurement of program duration, the permanent strategy is preferred for i > i*. Again regardless of these assumptions, the interim strategy is preferred only at low impermanence values and/or if program duration is measured at biased low program progress levels.

Solving the Allocation and Scheduling Programs: Systems Modeling as a Management Tool

While simulation models enable comparison between strategies, they require that the strategies first be defined. The simulation so far defined only two extreme and inflexible strategies. It is not likely, in a real program, that choice would be reduced to a very expensive permanent solution on the one hand or an ineffective impermanent solution, which is not even cheap, on the other, More likely, different levels of cleanup would be warranted at sites according to their different levels of health risks and environmental threats. There appears to be a trend emerging at EPA where cleanup would be approached in stages. The notion of "operable units" has been put forth in draft versions of the revised NC,. Essentially, the remedial response system will be approached in terms of phased-in cleanup, which for most sites will separate surface from subsurface cleanups (this is not necessarily technically sound). Cleanup will assume the form of a three-stage process.[1] This approach could be somewhat consistent with the "hedge-against-uncertainty" strategy defined earlier,

With cleanups structured into three-stage processes, a cleanup strategy could define or provide guidance for long-term allocation and scheduling policies, i.e., the tactics of the program. Decisions must be made about which sites are cleaned to what level and when each stage of cleanup is implemented. These are difficult management policy decisions for a number of reasons.

First, the crucial element for evaluating scheduling and allocation tactics is a measure of risk and/or cleanup goals. Such measures or goals could: 1) define the urgency and level of cleanup on a site-specific basis; 2) aid in designating sites requiring different levels of cleanup; 3) provide information for assessing cost effectiveness on an intersite basis, which could be used to measure the equity of cleanup schedules and allocations over all sites; and 4) maintain consistency within the cleanup strategy.

Second, it is necessary to relate various cleanup actions to levels of risk reduction or avoidance. Without defining such relationships, it is not possible to evaluate the site-specific cost effectiveness of cleanup options, In evaluating the cost effectiveness of the cleanup options it may be necessary to not only consider immediate risks but potential risks as well. A particular option may not appear very cost effective when considering only the near-term risks but may be extremely cost effective in light of longer term risks,

This complication touches on the third difficulty, that of evaluating cleanup action cost effectiveness on an intersite basis, The problems arise due to the interrelationship between allocation and scheduling. Limitations on budget, the availability of permanent cleanup technology, or the degree to which program infrastructure is developed will likely delay some remedial actions or some stages of remedial action. While initial responses may retard the deterioration of a site, some sites will continue to degrade. For this reason, scheduling and allocation of the Superfund among sites are deeply linked with projected or potential risks and costs of remedial measures. Trade-offs are likely between more extensive actions and initial responses in the near term, and between permanent cleanup actions at different sites in the long term,

The fourth management problem to address is the enormous number of possible allocation and scheduling sequences. There will be many possible cleanup action-risk reduction relationships, all of which may have different levels of cost effectiveness depending on when the actions are undertaken. The possibility of 2,000 to 10,000 sites and three stages of response represents well over a trillion possible sequences, Even though some will be patent nonsense and experience can eliminate others, a method for evaluating allocation schedules will be indispensable to efficient and equitable fund distribution, especially in a program of such magnitude and subject to intense public scrutiny.

Simulation could provide valuable comparative information among schedules if measurements of risk and the interrelationships of allocation and scheduling were reflected in the model. However, to arrive at preferred schedules, simulation methods would require defining them all and exhaustively testing them; this would most likely be computationally infeasible. Thus, simulation may not be the most useful tool for deciding management policies at the tactical level.

Fortunately, there are systems techniques that offer greater flexibility than simulation. Such techniques might include linear and nonlinear programming, dynamic programming, and decision analysis methods, all in a multicriteria context given that there would be more than one evaluation criterion. One of the largest applications of such mathematical models is in financial and investment planning, e.g., capital budgeting, cashflow analysis, portfolio management, etc. z Mathematical models would not require predefining tactics; the preferable tactics would be the output solution,

Modeling the system might begin with site classification, a step that might also be time dependent.

[1] *Inside E.P.A.*, June 15, 1984

[2] F J Fabozzi and J. Valente. "Mathematical Programming in American Companies: A Sample Survey," *Interfaces*, vol 7, No 1, November 1976, pp. 93-98

In addition to the classification scheme presented in EPA's ground water protection strategy, certain States, e.g., New York, have already implemented a site classification scheme as a method of allocating cleanup actions. The effects of deferring cleanup actions at particular site classes could be reflected by a deterioration coefficient. The deterioration coefficient might transform deferred sites from one classification to another. The variables in the model could relate specific classes of sites and clean up actions that would also be time dependent. Again it is the value of these variables in the model solution that would provide the tactics.

These variables might represent how many actions using a specific technology were applied to how many sites of a particular class in a given year. Remedial actions would also alter the site classification. This problem might be formulated to minimize program cost and duration subject to a cleanup goal (constraint. The level of cleanup might be increased to reflect the effects of increasing margins of safety, and solutions could be compared on the basis of *system* cost effectiveness. The solution-the distribution of remedial technologies over sites as a function of time-could also be used as a management tool. This could be done by more closely examining site-specific data to determine which sites would actually undergo cleanup using that type of technology.

While it may appear to be an ambitious undertaking, efforts are being taken already to incorporate limited but useful health information into decisionmaking. EPA is formalizing its risk assessment guidelines and attempts are being made to apply them to hazardous waste disposal site cleanup, Furthermore, site-specific hazardous waste information is accumulating as RI/FSs are completed. Other data are becoming available as the Hazard Ranking System is applied to more and more sites. For example the HRS has been applied to over 1,700 sites.[3] The next step is to develop and formalize a risk management strategy that would account for intersite cost-effective trade-offs over time. More extensive and systematic use of the information available now and in the future is desirable. Developing a strategy for the partial system that could be refined as health and environmental effects data are enhanced is also appropriate. To capture the dynamics of the system, a systems approach could be considered.

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[3] U.S. Environmental Protection Agency, "Extent of the Hazardous Release Problem and Future Funding Needs (CERCLA Section 301(a)(1)(C) Study," Final Report, December 1984.