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Off-Site Consequences of Radiological Accidents: Methods, Costs and Schedules for Decontamination

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Pacific Northwest Laboratory
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EXECUTIVE SUMMARY

The accident at Three-Mile Island resulted in increased attention by the public and by regulators to the off-site consequences of severe radiological accidents. The current study was commissioned by the Environmental Effects Branch of the Office of Nuclear Regulatory Research (NRR). It is a direct outgrowth of research conducted for NRR by the Pacific Northwest Laboratory (PNL) on the socio-economic impacts of serious reactor accidents.

One of the major findings of PNL's research on accident consequences is that decontamination costs and property losses resulting from a severe radiological accident could easily run into the billions of dollars, accounting for the majority of the off-site accident costs. At the time of these findings, however, only very limited means were available for assessing these costs. Also, it also seemed likely that the decontamination costs and property losses would be sensitive to site-specific factors, such as the land use of the affected property and its value. A final concern was that the evaluation of the decontamination costs was based on very rough estimates of the cost to decontaminate a few types of property with the same degree of contamination.

In view of the shortcomings of these evaluation techniques and the major contribution of decontamination costs and property losses to accident risk, the current research effort was undertaken. At the beginning of this effort, a search was conducted to determine the type of information that was available on decontamination procedures. It quickly became clear that information on well-documented procedures for decontaminating various materials was very limited. Some tests had been done with respect to nuclear weapons, but these results were not completely applicable, due to substantial differences in the nature of the contaminants. There were also documented procedures for using very powerful, but also very costly, techniques to decontaminate laboratory facilities and other small areas. However, because of the costs of these procedures and the specialized equipment used, they would be totally inappropriate for restoring an area of several hundred or several thousand square miles.

From these findings, a set of objectives was formulated to guide the present study. These were:

- to build upon the methods currently used by the NRC to estimate the decontamination and interdiction costs of a severe radiological accident. The method most commonly employed by the NRC staff and its contractors is the use of the CRAC2 computer model, which is based on the Reactor Safety Study (USNRC 1975).
- to collect information from both published and unpublished sources relating to decontamination procedures and to identify the circumstances favorable to the application of each.
- to develop sufficient information to describe the relationship between the physical inputs and the output of a production technique. This would enable us to identify the types of manpower and equipment required to carry out the decontamination efforts. Additionally,

acquiring the costs of these inputs would enable us to specify the costs of applying these procedures.

- to develop a methodology that would enable data commonly available by political subdivision to be imputed to the elements of a radial grid. CRAC2 utilizes a radial grid to characterize the accident site, and an analysis based on site-specific information requires the analyst to adapt population and property information to the radial grid. The difficulty of doing this can often become a major disincentive for conducting an analysis using site-specific information.

- to develop a computer program that is compatible with CRAC2 and that combines certain inputs from CRAC2 with other data to produce sufficient information to evaluate decontamination and interdiction costs. The program should also have the capability to assist in developing decontamination strategies.

In working toward these objectives, three major resources were developed at PNL for use in evaluating off-site accident consequences and in conducting site-restoration analyses. These are: 1) a reference data base; 2) a set of procedures and analytical tools for preparing a site database; and 3) a computer program, called DECON, to utilize the information in the two databases to produce analyses relating to the decontamination and interdiction of property.

The reference database contains information relating to the application of decontamination methods to surfaces. Currently, 347 methods have been defined for use on 22 different surfaces. For each method, the reference database includes the following information:

- the costs of applying the methods
- the efficiencies with which contaminants are removed
- the rate at which the methods are applied
- the quantity and type of labor required
- the quantity and type of equipment required
- the quantity and type of major materials required
- the costs for labor, equipment, fuel and materials
- the quantity of contaminated material requiring disposal
- the source(s) of the information

Except for the last item, the above data have been recorded in machine-readable format. The sources of the information have been provided to facilitate the updating of this database.

The second resource consists of procedures and analytical tools for preparing a site database. A major improvement of the current resources, as compared with CRAC2, is the ability to bring site-specific information into the analysis. Site-specific information is not often used with CRAC2 because it is not convenient to develop a site-specific database that can be used with it. The main reason for this is that a reactor accident under CRAC2 is located on a radial grid, and information must be supplied for each element of this grid. Unfortunately, site-specific information is commonly available by political subdivisions, but not by the elements of the grid.

The procedures developed for this second resource include methodologies and computer software to take demographic information available by political subdivision and use this to impute values to the elements of the radial grid. In addition, facilities have been developed for using, besides a radial grid, a rectangular grid and an irregular grid. The irregular grid is one in which each grid element has the same geographic boundary as a township or county. Thus, it makes direct use of the availability of information at the political subdivision level.

The third resource is a computer program for actually performing the decontamination analysis. The computer program, called DECON, has been designed to facilitate the planning of decontamination activities as well as to provide estimates of decontamination costs and property losses. The structure and features of DECON are described in this report. In addition, DECON's capabilities are demonstrated by applying it to a serious radiological accident at a hypothetical reactor site.

Among the information included in DECON is the following:

- the decontamination method used on each surface
- the rate at which the decontamination method is applied
- the type of labor used in the method
- the type of equipment used in the method
- the major materials required
- the efficiency of the method in reducing inhalation and external dose
- dose to radiation workers
- dose commitment from surface exposure
- year to decontaminate grid element to minimize property losses.

The capabilities of DECON include evaluating strategies to 1) vacuum exterior surfaces before they become rained on, 2) protect surfaces against precipitation, 3) prohibit specific operations on selected surfaces, 4) require pre-specified methods to be used on selected surfaces, 5) evaluate the tradeoff between cleanup standards and decontamination costs and property values, 6) affect decontamination costs by imposing different cleanup standards on different surfaces according to expected human exposure to the surface.

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Many individuals kindly volunteered their time and expertise in providing information and consultation concerning decontamination operations. Besides providing cost and productivity data, several people took the time to explain particular technologies and make constructive suggestions regarding how to accomplish a particular decontamination operation. Particular appreciation is extended to Bill Harding of the City of Los Angeles Department of Public Works; Jim Ajax and Jim Edwards of the City of Pasco, Washington, Department of Public Works; Don Steiner of Turco Products; Bob Weber of the U.S. Bureau of Land Management Interagency Fire Center in Boise, Idaho; Dick Pierce of the U.S. Forest Service in Portland, Oregon; and Dennis Jackson of the State of Washington Department of Transportation.

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Finally, we wish to thank Debra Young, Beverly Johnson and Dorothy Matthews for their tireless efforts in typing this report and its earlier drafts. To all of the many other individuals who assisted in the various aspects of producing this report, we extend our sincere thanks. And we, the authors, are alone responsible for any errors contained in this work.

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1.0 INTRODUCTION

This study was conducted by the Pacific Northwest Laboratory (PNL) for the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES). It was undertaken to provide the NRC with improved technical information and enhanced analytical capabilities regarding site restoration following a major radiological accident at a nuclear power plant.

1.1 ORGANIZATION

This report is organized as follows. In the next section we present an overview of three major resources developed at PNL for conducting a site restoration analysis for a radiologically contaminated area. The resources consist of:

- a body of technical information relating to the decontamination of property
- a set of procedures and software tools to facilitate constructing a database of information specific to the radiologically contaminated site
- computer software for analyzing the information.

We refer to the first resource as the reference database. The site-specific information on the contaminated site comprises the site database, and the program for analyzing the information is called DECON.

Chapter 2 describes the reference database. The chapter begins with a description of the database contents, which consist of numerical information relating to many aspects of decontamination procedures. The concepts embodying these data are discussed, and the underlying assumptions are made explicit.

The site database is addressed in Chapter 3. Unlike the reference database, which contains detailed but general information that can be applied to nearly any site, information in the site database will be site-specific. This means that the contents of the database for one site will generally be inappropriate for other sites. Rather than focusing on actual values in the site database, then, we concentrate our efforts on evaluating methods for characterizing the accident site and on developing procedures for producing the site-specific information.

In Chapter 4 a description of DECON and its supporting software programs is presented. In addition to discussing the logical flow of DECON, its various features and capabilities are also described. The supporting software programs have been developed for maintaining and updating the reference database, and for preparing the site database.

The final chapter demonstrates the use of these three analytical resources by applying them to a case study of a serious reactor accident. Although this study is not based on any particular reactor site, it provides a realistic exercise in both assessing the consequences of the accident and planning a strategy for coping with the cleanup effort.

This report also contains several useful appendices. Appendix A provides a highly detailed description of how decontamination costs, rates and inputs were derived. A discussion of the assumptions and principles underlying the development of the decontamination efficiencies is presented in Appendix B. The preponderance of the data contained in these appendices was developed from information supplied by original sources. To facilitate updating of the reference database, these sources, along with their telephone numbers, are supplied in Appendix C.

The next three appendices provide detailed information about the software programs. Appendix D provides technical information on the software for maintaining and updating the reference database. Appendix E pertains to the site database. It describes the methods for characterizing an accident site, and it presents the technical relationships used in those methods where information must be imputed to geographical areas. Appendix F contains a detailed description of DECON.

1.2 BACKGROUND

This research was motivated by the NRC's need for more reliable information relating to the socioeconomic consequences of accidents at nuclear power plants. This information is applied in evaluating off-site accident risks posed by nuclear power plants. Major policy areas in which reactor accident risks need to be evaluated include the development and implementation of reactor safety goals and the assessment of alternative sites for yet-to-be constructed nuclear plants. To the extent that policy decisions in these areas are based on cost/risk criteria, the accident consequences to property must be evaluated since they comprise a significant component on the cost side. In addition, plant licensing requirements include the preparation of environmental impact statements (EISs), and these must also address the potential impacts of radiological accidents.

A severe radiological accident, although extremely unlikely, has the potential of causing early injuries and deaths, long-term cancers, genetic effects, and widespread damage to property. The off-site property costs of such an accident could run into the billions of dollars. To estimate these costs, the NRC often relies on a sophisticated computer model called CRAC2. This model simulates a radiological accident and provides estimates of evacuation, relocation, crop interdiction, milk interdiction, land interdiction, and decontamination costs, as well as various health effects.

The estimates from CRAC2 indicate that the land interdiction and decontamination costs tend to dominate the other estimated accident costs. It is therefore reasonable that these costs should be emphasized in any attempt to improve on the information provided by CRAC2. In addition to the cost aspects of such an accident, widespread social disruption could be expected. However, before the contaminated areas can be resettled, they will have to be decontaminated. The time schedule for decontaminating these areas should consequently be of considerable interest.

1.3 OBJECTIVES

This report has several major objectives. The first is to build upon the methods currently used by the NRC to estimate the decontamination and interdiction costs of a severe radiological accident. As already noted, the method most commonly employed by the NRC staff and its contractors is the use of the CRAC2 computer model, which is based on the Reactor Safety Study (USNRC 1975).

The second objective is to collect and present information from published and unpublished sources on acceptable decontamination procedures and the circumstances favorable to the application of each. This part of the study involves conducting a literature search and interviewing individuals having experience and/or expertise in these areas.

The third objective is to develop sufficient information to describe the production and cost functions for each decontamination procedure. A production function describes the relationship between the physical inputs and the output of a production technique; that is, it describes how the output changes as the quantity of one or more inputs is changed. The cost function, on the other hand, describes the minimum cost for producing each output quantity. Once input costs are known, cost functions can be derived directly from the production function.

The fourth objective is to develop a methodology that will enable data commonly available by political subdivision to be imputed to the elements of a radial grid. CRAC2 utilizes a radial grid to characterize the accident site, and an analysis based on site-specific information requires the analyst to adapt population and property information to the radial grid. The difficulty of doing this can often become a major disincentive for conducting an analysis using site-specific information. In addition to developing the methodology for making this imputation, the methodology is to be embodied in a computer program.

A final major objective is to develop a computer program that is compatible with CRAC2 and that combines certain inputs from CRAC2 with other data to produce a variety of information relating to decontamination activities at the accident site and the effects of the accident on property values. The computer program is to significantly exceed the capabilities of CRAC2 in providing an accurate and informative analysis of decontamination activities and property value effects.

1.4 METHODOLOGY AND OVERVIEW

Research that PNL has conducted over the past three years on off-site consequences of severe radiological accidents has shown that: 1) decontamination costs and property losses could be in the billions of dollars, accounting for the majority of all off-site costs, other than health effects; and 2) research tools for obtaining reliable estimates of these costs and for planning decontamination strategies in the event of such an accident have until now been unavailable. Because of this apparent importance of decontamination costs and losses associated with property, the NRC made a decision to support the development of a set of comprehensive research tools for analyzing and assessing post-accident decontamination activities and property losses.

In considering the problem of restoring a radiologically contaminated site, it was decided to implement a decision framework based on sound economic principles. The foremost principle that was applied was that all decisions should promote minimizing the net present value of the social costs of the accident. A decision process based upon this principle would encompass effects of an accident other than those concerned directly with site restoration; health effects costs are the most important among these.[1]

The principle actually applied in this study is to minimize direct site restoration costs and other property losses caused by a reactor accident. This approach allows the cleanup criteria to be set prior to and independently of the costs of cleanup and the property losses. However, because stricter criteria will generally result in higher cleanup costs, the policymaker may wish to scrutinize this tradeoff before finalizing the cleanup criteria.

The next step in constructing the decision framework was to consider the types of decisions that would need to be made. A severe radiological accident could contaminate thousands of square miles of property. As already noted, potential losses to society could be in the billions of dollars. In view of this situation, two central concerns would likely emerge: 1) recovery costs would need to be kept manageable, and 2) personnel and equipment in relatively abundant supply should be utilized so that the recovery process would not be delayed. In view of these likely concerns, a search was made for effective decontamination procedures that were relatively inexpensive and that made use of widely available equipment and personnel.

Our search for decontamination procedures meeting these two requirements was generally successful. Published sources provided information on the decontamination efficiencies of several techniques applied to a variety of surfaces. Unfortunately, this information was deficient in several respects, but it did provide a nucleus around which to build a more comprehensive and useful database. Furthermore, one of the insights obtained from these published data was the idea of applying the decontamination procedures to surfaces rather than to objects.

1.4.1 The Reference Database

The next logical step was to prepare an inventory of decontamination procedures and to identify the surfaces on which they could be applied. Well-defined procedures for decontaminating surfaces are henceforth called decontamination <u>operations</u>. Table 1.1 presents a list of the operations currently

[1] For a detailed discussion of the socioeconomic consequences and social costs of reactor accidents, see (Tawil et al., 1983); a detailed discussion of the health effects costs of reactor accidents is presented in (Nieves et al., 1983).

implemented and the symbol for each. Where more than one operation is described for a symbol, the actual operation referenced will be clear from the context in which it is used. The operations for automobiles are separately identified for clarity.

TABLE 1.1. Decontamination Operations

A	Plow	P	Thin Asphalt/Concrete Layer
B	Vacuum Blast	Q	Very High Pressure Water
C	Strippable Coating	R	Remove and Replace
D	Defoliate	S	Sandblasting
E	Leaching, EDTA	T	Surface Sealer/Fixative
F	Foam	U	Hydroblasting
G	Three-Inch Asphalt and	V	Vacuum
G	Cover with 6" Soil (No Trees)	W	Low Pressure Water
H	High Pressure Water	X	Scrape 4"-6"
I	Steam Clean	Y	Deep Plow
J	Wash and Scrub; Shampoo Carpet	Z	Remove Structure
K	Resurface	g	Cover with 6" Soil (Trees in Place)
L	Leaching, $FeCl_3$	h	Hand Scrape
M	Close Mowing	t	Fixative, Aerial Application
N	Clear; Harvest	v	Double Vacuum
O	Plane, Scarify; Radical Prune	x	Double Scrape

Operations to Automobiles

D	Detailed Auto Cleaning	T	Tow
E	Clean Engine with Solvent	V	Vacuum
I	Steam Clean	W	Water
J	Wash and Scrub	c	Drive Auto Out
K	Repaint	m	Auto Transport Truck
R	Replace/Reupholster	v	Double Vacuum
S	Sandblasting	z	Remove Interior/Clean/Replace

As noted, decontamination operations are applied to surfaces. The surfaces that are currently implemented are presented in Table 1.2. While some of the surfaces listed in this table are actually composed of several surfaces--e.g., orchards and auto interiors--it is reasonable to assume that the composition of surfaces within each surface type does not vary significantly. Thus, for example, it is assumed that the leaves, branches and ground in one orchard will require essentially the same treatment as the leaves, branches and ground in another equally contaminated orchard with the same land area.

Each of the operations identified in Table 1.1 will apply only to a subset of the surfaces listed in Table 1.2. In addition, an operation with the same name but applied to a different surface is treated as a different operation. Thus, for example, vacuuming a roof is a distinct operation from vacuuming a concrete street.

TABLE 1.2. Surface Types Currently Implemented

1. Agricultural Fields	12. Interior Walls, Concrete
2. Orchards	13. Streets and Roads, Asphalt
3. Vacant Land	14. Streets and Roads, Concrete
4. Wooded Land	15. Roofs
5. Exterior Walls, Wood	16. Lawns
6. Exterior Walls, Brick	17. Auto Exteriors
7. Floors, Linoleum	18. Auto Interiors
8. Floors, Wood	19. Auto Tires
9. Floors, Carpeted	20. Auto Engine and Drive Train
10. Floors, Concrete	21. Other Paved Surfaces, Asphalt
11. Interior Walls, Painted	22. Other Paved Surfaces, Concrete

In decontaminating a surface, it seems reasonable in many cases to use a sequence of operations rather than just a single operation. For example, before treating a concrete street with high pressure water, it may make sense to vacuum it first. Similarly, it may be cost-effective first to apply a fixative and then to clear vacant land before scraping dirt from it. An effective decontamination strategy will likely include such sequences of operations rather than only single operations. We therefore define a sequence of one or more operations as a decontamination method.

The reference database consists of information on decontamination methods. The information it contains can generally be applied to any radiologically contaminated site without making alterations to the data. The contents of the reference database are described in the next chapter, along with the assumptions that underly the reference data.

1.4.2 The Site Database

The site database contains information that pertains specifically to the contaminated site. To facilitate analysis of the site, the contaminated area is first partitioned into a number of subareas. Since we assume that the level of contamination is constant throughout each subarea, the reasonableness of this assumption will depend on the size selected for these subareas. We consider three alternative ways of partitioning the contaminated area. They are: a grid with area elements of equal size and shape; a radial grid; and a grid with irregularly sized grid elements whose boundaries conform with those of political subdivisions. The advantages and disadvantages of each of these is discussed in Chapter 3.

To conduct the decontamination analysis, three major types of information must be provided. They are:

- the type of property that is contaminated
- the degree to which the property is contaminated
- the value of the contaminated property.

This information must be supplied for each of the grid elements, and the size, shape and number of the grid elements will depend upon the analyst's choice of grid.

It is recalled that the reference database provides information on the decontamination of surfaces. However, a look at the list of surfaces in Table 1.2 makes it clear that such information would be available for few if any reactor sites. On the other hand land use information is often compiled by state and local agencies. This land use information commonly gives the allocation of various land uses among political subdivisions, such as townships and counties. We have opted for an approach that can take advantage of the general availability of land use information. To implement this appraoch, two major obstacles need to be overcome: 1) a mechanism must be created for transforming land use information into information on surface types; and 2) a procedure must be developed that enables information obtained at the county or township level to be imputed to the geographical areas represented by the grid elements. Given this approach, an important component of the site database is land use information.

The mechanism that has been developed to transform land use information into surface type is based on observed relationships between land uses and their constituent surfaces. For example, property designated residential is comprised of exterior walls (wood, brick and concrete), floors (wood, carpeted and concrete), interior walls (painted and concrete), roofs, lawns, and "other paved surfaces" (asphalt and concrete). The relationships between types of property and their surface components is discussed in Chapter 3.

The site data base must also provide information on how severely the property is contaminated. This information may consist either of radiological survey data taken directly from the field, or of predicted values produced by computer models that simulate reactor accidents and their effects.

Finally, the site database should include information on the value of the property that is contaminated. Because the basic principle underlying our appproach is to minimize the net present value of site restoration and other property costs caused by the reactor accident, property value information is needed to determining <u>when</u> a property should be decontaminated. Several factors affect this decision. First, the natural radioactive decay process causes the effective dose to decline over time. This suggests that delaying decontamination may make it possible to utilize less costly procedures. This opportunity will be greater, the larger the proportion of the total dose that derives from radionuclides with short half-lives. A second factor relates to the weathering process. Weathering has the effect of reducing the effective dose in any particular area by carrying contaminants deeper into the soil via precipitation and by spreading wind-borne contaminants over an increasingly wider area. Like the decay process, weathering also offers advantages to deferring decontamination. On the other hand, such delay causes potentially useful property to remain in disuse. The longer is the delay and the more valuable is the property, the greater is the social cost that results from loss of use of the property. These three effects must be weighed together in determining when a property should be decontaminated.

1.4.3 DECON

DECON is a computer program that takes the information in the reference data base on decontamination procedures and systematically applies it to the information in the site database. DECON reports the site restoration costs, the decontamination procedures used, the manpower and equipment required, property losses, a decontamination schedule and a variety of other information that is potentially useful in developing a site restoration strategy. A detailed discussion of DECON is presented in Chapter 4.

2.0 THE REFERENCE DATA BASE

In this chapter we describe the development of the reference database. We earlier stated that the main principle underlying our approach in developing a site restoration strategy is to minimize the net present value of the site restoration and other property costs caused by a radiological accident. These costs can be minimized via several choice mechanisms. First, it is necessary to select a procedure for decontaminating each surface. The choice will depend in large part on how little residual contamination will be permitted, the effectiveness of the procedure in removing contamination, and the cost of applying the procedure. Generally, the least costly method that reduces contamination anywhere below the permissible level will be the top choice. However, other factors may also need to be addressed. For example, the procedure may require specialized equipment that is not available in sufficient quantities. Or decontamination procedures that rely on the use of water may contaminate underground water supplies or water treatment facilities. Such external effects need to be considered to ensure that the selected method will not be more costly overall than other available alternatives.

Another choice that must be made relates to when decontamination should take place. As noted in the previous chapter, at least three factors affect this choice. Radioactive decay and weathering offer opportunities to reduce the cleanup costs by deferring the decontamination into the future. Both of these natural processes generally work to reduce exposure over time; and the less the exposure, the less drastic measures will be required to return the site to some given level of residual contamination. On the other hand, while the property is awaiting decontamination it cannot be used. This loss of use of the property will be costly; the more valuable the property and the longer that it lies in disuse, the greater will be the cost. By carefully choosing when to decontaminate a property, losses can be minimized. In addition to the factors mentioned, however, there are other relevant considerations. For example, except in unusual circumstances, it will not generally be desirable to decontaminate a property while all of the surrounding property remains contaminated. Another example relates to the political pressure that will be brought to bear by those suffering property losses. To the extent that the decontamination costs will not be borne directly by those owning contaminated property, there will be pressure to decontaminate the property as quickly as possible.

A decision also must be made regarding how thoroughly the contaminated area is to be restored. The less the allowable residual contamination, the more costly will be the cleanup. While the current approach does not provide a mechanism for selecting the cleanup standard, it does produce sufficient information to elucidate the relationship between decontamination costs and health risks from residual contamination. Thus, the selection of the cleanup standard can be made using the best available information.

2.1 CONTENTS OF THE REFERENCE DATABASE

To implement the choice mechanisms described above, and thus to facilitate a cost-minimizing site restoration strategy, it is necessary to have available a comprehensive database relating to decontamination activities. At minimum, the database must contain information for determining the cost of using a decontamination procedure and the efficiency of the procedure at removing contaminants. The database that has in fact been developed contains the following information:

- cost of the inputs used in each decontamination operation (measured in dollars per unit area decontaminated)
- the efficiency of each decontamination method (measured as a percent)
- output rate of each decontamination operation (measured as area decontaminated per shift-hour)
- physical inputs to each decontamination operation (measured in manpower, capital and material requirements).

Throughout this report we use the term "operation" to refer to a basic single decontamination procedure. Examples are vacuuming pavement and hosing roofs. Some operations involve more than one step. For example, the operation of removing and replacing a roof involves the three separate steps of applying a fixative, removing the roof, and replacing the roof. One or more operations executed on a single surface, constitute a "method". For example, the operation of vacuuming pavement followed by the operation of resurfacing the pavement constitutes a unique method. This designation is important because the particular sequence of operations comprising a method determines the net decontamination efficiency.

2.2 DECONTAMINATION OPERATIONS, COSTS, AND EFFICIENCIES

Decontamination operations and methods have been developed for all of the surfaces listed in Table 1.2. This section describes the principal operations for decontaminating these surfaces. The average cost per square meter, the average number of square meters decontaminated per hour, and the composition of cost in terms of physical inputs are presented for each operation. In addition, the efficiencies for each operation are briefly discussed.

2.2.1 Decontamination Costs

It is important to be clear about what the cost estimates developed in this report do and do not represent and to explain some of the general methods used in compiling these estimates. The cost estimates presented here refer only to the direct costs of actual decontamination activities. Not only are the decontamination activities just one source of costs resulting from a major reactor accident, but the direct costs of decontamination activities are only a subset of total cleanup costs. For example, in estimating the costs of applying a low-pressure water wash to pavement, we have omitted the costs of protective clothing, radiation monitoring, and health costs.

The direct costs of the decontamination operations have also been somewhat narrowly defined. Many of the operations give rise to contaminated materials that require transport to a disposal site and subsequent disposal. Examples are scraping of vacant land and replacement of pavement and roofs. Because transport costs will depend in large measure on how far the contaminated materials must be transported, and because this distance would likely vary from situation to situation, transport costs are not included in the cost estimates of the operations. However, the reference database does contain sufficient information to enable the transportation costs to be estimated. Specifically, for each relevant operation an estimate is developed of the volume of contaminated material that must be disposed of for each unit area of the surface decontaminated. Also, cost estimates based on distance have been developed for hauling. With regard to disposal, because these materials may be disposed of in different ways, the disposal problem is also treated separately.

Another characteristic of the cost estimates is that they pertain only to the decontamination of the surface under consideration. In practice, the contaminants originally on a surface may be transported to surrounding surfaces due to factors other than weathering. This phenomenon may occur either prior to decontamination or during the decontamination process itself. For example, if roofs are decontaminated with a method that relies on water, no costs are included for treating the contaminated water. One reason for excluding these costs is that when several alternatives for dealing with the water are available, one technique may not be preferred in all circumstances. In the case of using water on roofs, allowing the runoff to penetrate into the ground will be perfectly adequate in some situations; in other situations, the runoff might need to be collected in drums via a gutter system; in still other situations, disposal in the sewage system may be the best choice. Because of uncertainty about the preferred method, excluding the cost of disposing of the contaminated water was felt to be the most reasonable approach. This way, the costs for decontaminating roofs--as this operation has been defined--retain their accuracy; the costs for dealing with the contaminated water can be added later once the disposal method has been selected.

A second reason for excluding these ancillary costs is that when the contaminants are transported to other surfaces, the cost of dealing with them will depend on the type of surface to which they have moved. Removing contaminated runoff from soil represents a very different problem from removing the same runoff from a paved surface.

Still another reason relates to the contamination level on the surface that receives the transported contamination. If the surface is at the outer fringe of the contaminated area, the added contaminants may be sufficiently dispersed so that they are of no concern. On the other hand, if the contaminants are added to a surface that is already heavily contaminated, the decontamination costs for this surface could rise dramatically.

Potential problems due to transmigration of contaminants can be minimized through mitigating actions. For example, the application of a fixative to heavily contaminated surfaces soon after the accident will significantly diminish movement of contaminants prior to and during decontamination. Decontaminating surrounding lawns and pavements after roofs have been decontaminated, and decontaminating downwind areas after upwind areas will also reduce potential problems.

The costs that have been developed for all of the operations are based on the assumption that large areas require decontamination. This means that the cost estimates fully incorporate all economies from large-scale operations. If only small areas need to be decontaminated, a premium should be added to the costs to reflect the scale of operations.

Working in a contaminated environment will usually be more costly than working in an uncontaminated environment for at least three reasons. First, personnel and equipment will be subject to radiation control measures. Personnel may be required to wear anti-c's or other protective gear; putting on and removing this gear will take time out of every work shift. Equipment will also need to be decontaminated periodically, and probably often. We have allotted one hour per eight-hour shift for these radiation control measures. A second reason is that protective clothing will reduce worker productivity, which in turn will increase decontamination costs. This will be particularly true in warm and hot weather. Currently, we make no allowance for this effect. A third reason is that workers will likely demand a premium to work in a contaminated environment. Because we have not investigated what an appropriate premium might be, we have excluded this effect from our cost estimates. (However, in the software that utilizes this database, we have made it very easy to make adjustments to labor and equipment costs to reflect these and other factors.)

The dollar amounts of these costs are expressed in terms of 1982 price levels. To the extent that price levels change, the figures given in this report should be adjusted by using a price index or by reestimation. The information contained in Appendix A shows how these costs have been developed. In many cases, the information underlying these costs shows significant variation, and in a few cases the information is inconsistent. We recommend that in cases such as these the cost estimates be viewed as relative measures. Thus, for any particular operation, while the cost estimate could prove to be somewhat over or under actual costs, the ratio of the estimated costs of any two operations should be a good indicator of the actual cost ratio.

2.3 PROCEDURES FOR INTERDICTED AREAS

In interdicted areas it would usually be good practice to apply a fixative to all exterior surfaces to prevent decontaminated areas from being recontaminated. Aerial application of road oil appears to be the most practical method to accomplish this.

The application of road oil by aircraft requires an airfield with facilities to perform routine airplane maintenance and to rapidly load road oil on the planes in large volume. Both large planes such as DC-7s with a 3,000-gallon capacity and small planes with a 350-gallon capacity can be used. Flight crews for the larger planes consist of two people, while one person is sufficient for the smaller planes.

Application of several thin coats of road oil to build up an average coverage of 0.4 gallons per square meter should assure fairly uniform coating. The cost of aerial application at this coverage rate ranges from $0.11 to $0.24 per square meter in 1982 dollars, depending primarily on the type of aircraft used. Adding the cost of the road oil at $0.31 brings the total cost per square meter to $0.42-$0.55. The expected cost is therefore about $0.45 per square meter. The rate of application will be from 1,808 to 16,461 square meters per hour, again depending on the type of aircraft used. Since the larger aircraft is more likely to be used, we take a rate of 14,000 square meters per hour as representative.

2.4 DECONTAMINATION COSTS FOR VARIOUS SURFACES

In this section we consider appropriate decontamination operations for the surfaces listed in Table 1.2. For each operation, a discussion is provided on the costs, inputs and coverage rates. Also addressed are the advantages, disadvantages and special conditions that may attend the use of these operations. Costs and rates for the various operations are summarized in tables in Section 2.4.1.11.

2.4.1 Paved Surfaces

Four types of pavement surfaces are considered in this report. Asphalt roads and concrete roads refer to large paved areas constructed of those materials. In addition to highways, streets, and roads, these surfaces include large commercial parking lots and other large paved areas. The other types of pavement surfaces are designated here as other asphalt and other concrete. These surface are smaller in area than roads. In addition, access to them may be limited. As a result, the options with respect to particular equipment and techniques may be limited. Therefore, while the basic nature of the operations for other asphalt and other concrete are the same as for asphalt and concrete roads, the production rates in terms of square meters per hour are lower, and the costs in terms of dollars per square meter are higher, on other paved surfaces.

2.4.1.1 Mobile Vacuuming

Mobile vacuum street sweeping as done by municipal public works departments, airports, and highway departments is a practical technique for reducing radioactive contamination of pavement. While the decontamination efficiency of vacuuming streets is lower than most other operations, the relative cost per square meter of vacuuming is so low that it would be used alone or in conjunction with other procedures in essentially all pavement decontamination methods.

The reported cost figures for vacuuming ranged from $0.0020 to $0.0057 per square meter, with $0.0043 being a representative estimate. Subsequent vacuumings over the same surface are likely to cost somewhat less per unit area than the first pass, though they will also be less effective.

The rate of surface treatment is highly variable, with sources reporting rates from 7,177 to 29,462 square meters per hour. A rate of 8,632 square meters per hour is a reasonable expectation. For smaller paved areas or areas with restricted access, it may be necessary to use other equipment such as an industrial parking lot vacuum.

2.4.1.2 Low-Pressure Water Wash

Washing paved surfaces with water will remove about 95 percent of the radioactive contamination. Water achieves its effectiveness primarily as a consequence of the fact that many radioactive particles solubilize readily in water. Water also has the ability to reach into crevices which might shield the contaminants from the air blasts of a vacuumized street sweeper or from other mechanical decontamination methods.

The least costly way to effect a water wash of this sort is to employ standard mobile street flushers. The unit cost for this treatment is about $0.0013 per square meter. One reason the cost in terms of surface area is so low is that not only do these machines move along at an average speed of over three miles per hour, but they can flush half a street width, 20 feet, at a time.

While this method is quite cost effective in terms of reducing pavement contamination, there is a possible drawback to this procedure which could greatly limit or even prevent the use of street flushing. This problem concerns the resulting contaminated water. If there are curbs and storm drains, it may be desirable or acceptable to allow the contaminated water to drain into the storm sewer system. The hazard of radiation in underground mains to people on the surface would be significantly mitigated by the shielding of the intervening pipe, soil, pavement, and so forth. The storm drain system could also serve as a mechanism to gather the contaminated water from various locations to a central site where the water could be treated or stored. In the absence of storm drains, it may be acceptable or desirable to let the water run off the pavement and percolate into the soil. However, because of the threat to subterranean water supplies or for other reasons, it may be necessary to prevent as much as possible any seepage of contaminated water.

The issue of the appropriate handling of contaminated water bears on all the water-using decontamination techniques including those on roofs and lawns. Indeed, even rain could create large volumes of contaminated water. A thorough treatment of this question, however, is beyond the scope of this study.

2.4.1.3 High-Pressure Water

Hosing paved surfaces with water at pressures in the range of from 80 to 120 pounds per square inch adds significant scouring action to the solubilizing attribute of water. However, the pressure can also act to drive the contamination further into pavement.

The way in which a high-pressure wash of pavement would be done would depend primarily on the facilities available. If fire hydrants on high-pressure water mains are available, a relatively inexpensive way to accomplish this procedure is to simply equip teams of two or three individuals with a few hundred feet of firehose. They can hose all pavement surrounding the hydrant within the reach of the hose. After hosing one area, they would move on to the next hydrant. The estimated cost of this method is $0.021 per square meter.

Where there are no hydrants or accessible high-pressure water mains, fire department equipment could be used to boost the water pressure and, if necessary, to transport water to the hosing site. However, the accumulated cost data indicate that this is a costly operation. Even if an on-site water supply is available, using a pumper truck to provide the required water pressure would raise the cost per area about sevenfold over the manual hosing method just described. If tanker trucks to supply water to the pumper trucks are also required, the cost will rise to about $0.32 per square meter.

A third method is to equip tanker trucks with a pump and a spray bar. This would allow a single piece of equipment to hose a swath ten feet wide while moving forward. Even with nearly half the time spent refilling the tanker, the cost of this method is comparable to that of manual hosing. This method is the basis for deriving representative cost and rate figures. With an application of 0.18 inches of water to the road, the cost per square meter would be around $0.020, and the rate of surface coverage would be about 2,578 square meters per hour.

2.4.1.4 Very High-Pressure Water

Greater scouring and, therefore, greater removal of embedded radioactive particles can be achieved with a very high-pressure blast of water. Very high pressure refers to a pressure of about 400 pounds per square inch. Higher pressures would tend to erode the pavement.

Fire equipment pumps are customarily set to pump at around 100 pounds per square inch, but can be configured to pump at four times that pressure. However, in doing so the volume of water drops sharply. In order to maintain an adequate flow of water at very high pressure, it is necessary to use a large pump powered by a six- or eight-cylinder engine. Such a pump would be mounted on or towed behind a tanker truck equipped with a spray bar. This would permit the truck to spray a path one lane wide while driving forward. To apply enough water per unit area, the truck's speed would be about one mile per hour. The cost per square meter would be about $0.022.

2.4.1.5 Foam

An acidic lather-like foam can be an effective method to lift contaminants out of pavement. The foam works by inducing reverse osmosis. An acid concentration gradient is maintained through the foam's thickness. As long as the acidity above is greater than that below, less acidic compounds originating on the pavement surface will move up into the foam, tending to erase the acidity gradient.

The foam can be sprayed from a properly equipped tanker truck. After allowing the foam to remain on the pavement for at least an hour, it can be vacuumed with a vacuumized street sweeper. A foam suppressant will allow the sweeper to pick up a large volume of foam by reducing it to a liquid form.

This operation will cost in the neighborhood of $0.09 per square meter. Over 90 percent of the costs are for the necessary chemicals. Because the operations of foam application and removal can be done from vehicles, the rate of treatment, over 12,000 square meters per hour, is relatively high.

Following an initial vacuuming, a foam treatment is estimated to remove about 30 percent of the remaining contamination if these operations are accomplished before any rain or snow.

2.4.1.6 Strippable Coating

An interesting decontamination method involves spraying or rolling a special chemical solution onto the surface to be decontaminated. After the liquid dries, it can be peeled off like cellophane tape. This strippable coating will take with it much of any loose surface contamination.

Besides their use as a decontaminant, these coatings are also useful as a fixative that can be easily removed and as a protective coating to minimize contamination. For example, before entry into a contaminated area, vehicles could be coated with a peelable coating. This would protect the actual surface of the vehicle from radioactive particles. By peeling off the coating, nearly all the contamination would be removed.

The liquid coating solution could also be sprayed on roads in much the same way as high-pressure water is sprayed on roads from a tanker truck with pump and spray bar. Mechanical removal of the coating using a specially equipped moving vehicle may be within the realm of possibility. If such a fairly efficient removal using a motorized vehicle can be perfected, the cost per square meter would be about $1.90. Because the chemicals are so expensive, they would account for nearly all the cost. Removal of the coating by hand would be slow and would raise the cost somewhat, but the percentage increase in the cost would be small.

Besides the cost, there are some additional considerations about this approach to decontamination that need to be mentioned. While there are a number of manufacturers of this type of material, it is not clear that there exist sufficient inventories and manufacturing capacity to supply quantities on the scale that would be meaningful in the cleanup of a major reactor accident. Further, practical experience with this material on large areas of pavement is limited enough so that there is considerable uncertainty as to its removal efficiency in such applications.

2.4.1.7 Planing

An obvious way to remove the radiation hazard of contaminated pavement is to remove the pavement itself, or at least to remove the contaminated surface. An assortment of road construction operations are discussed in this report. Some can be used alone or in combination with other operations.

Planing is an operation in which the top surface of the pavement is removed. Planers are machines, varying in width, which remove pavement by abrasion. Planers are used to remove from one to six inches of pavement surface. In the present case we are only interested in removing one inch.

While some planers are equipped with a water spray for dust suppression and cooling, a problem with other planers is that they tend to generate much dust which, in a decontamination operation, would contain radioactive particles. This dust, then, could lead to significant recontamination of the surfaces just planed unless special measures are taken. Affixing rubber containment skirts around the base of the planing machine and attaching a high-power mobile vacuum intake hose would greatly alleviate the problem. The mobile vacuum would continuously draw in the dust from the grinding. These vacuums normally operate with adequate filtration (down to one micron) so that most of the contaminants would be collected.

Planing with dust control would cost around $2.43 per square meter for an asphalt surface and about $2.91 per square meter for a concrete surface. The surface after planing is rough, but it is driveable. In most cases planing would be followed by laying a thin (one inch thick) coat of asphalt pavement over the planed road surface.

2.4.1.8 Thin Surface Coatings

Thin surface coatings such as tack coating, sealer, or road oil can act as fixatives durable enough to permit road traffic. The costs of these coatings range from about $0.30 to $0.54 per square meter. Of these coatings, road oil has been used successfully as a durable fixative on desert soil at the Nevada Test Site.

2.4.1.9 Asphalt Pavement Overlay

Applying a layer of asphalt has three major functions. First, the asphalt layer will prevent resuspension of radioactive particles. Paving therefore has a high efficiency with respect to the inhalation-ingestion pathway. Second, the asphalt provides a certain amount of shielding and thereby is effective in terms of the exposure pathway. The effectiveness naturally increases with the thickness of the asphalt layer. Three inches of asphalt will reduce exposure by about half. Third, paving can be advantageously combined with other operations. For example, paving, following planing, not only removes, fixes, and shields the radiation, it also restores the pavement surface.

Two asphalt paving operations are considered here. The first is a minimal-thickness asphalt overlay. For an existing asphalt base, the minimum-thickness asphalt overlay is one inch. On a concrete base the minimum thickness is two inches. The second paving operation is a medium-thickness pavement overlay. The asphalt layer applied is three inches thick.

The costs and rates of these operations are usually estimated in terms of the volume of asphalt applied. Thus, covering 100 square meters with asphalt one inch thick would normally take the same time as paving 50 square meters two inches thick. The cost of a thin overlay on asphalt roads comes to $2.02 per square meter, and because of the greater thickness, the cost is twice that on concrete roads. About 90% of the cost is for the asphalt material. Labor and equipment comprise only about 5% each.

2.4.1.10 Remove and Replace

For severely contaminated paved surfaces, the most costly operation - pavement removal and replacement - may be indicated. The operation consists of two distinct steps, both with fairly similar production rates. The material cost, however, makes replacement about five times more costly than removal. Replacement includes applying a six-inch thick layer of pavement.

2.4.1.11 Summary of Pavement Decontamination Operations

Tables 2.4.1.11.1 through 2.4.1.11.4 present the basic cost data for the various decontamination operations for the pavement surfaces.

2.4.2 Roofs

The cost estimates for the decontamination of roofs, as opposed to the estimates for paved surfaces, are subject to three important considerations. First, in most cases, treating roofs to remove radioactive particulates will cost much more per unit area than will a procedure of equal effectiveness for pavement. This is due largely to the poor accessibility and the discontinuity of roof surfaces.

Second, there is a greater variety in the factors affecting roof cleanup costs than there is affecting pavement cleanup costs. Important variables include the material with which the roof is constructed, the slope of the roof, the height of the roof, and the size of the roof. In general, the costs of roof decontamination were figured with the assumption that roofs were for single-family homes, one to two stories in height.

The third consideration is that there is very little accumulated experience in most of the roof cleanup operations. This means that the cost and rate estimates will be more vulnerable to error.

Costs of the various operations for decontaminating roofs are presented in Table 2.4.2.1. Vacuuming does not remove as much of the contamination as other methods, only about 60 percent, but it is a relatively low-cost procedure and it does not create any major problems as might be the case with methods using water.

A step up from vacuuming, in terms of effectiveness, is a low-pressure water wash. This could be accomplished for about $0.23 per square meter and would reduce the contamination by about 95 percent. Both vacuuming and low-pressure hosing require very little in the way of equipment. Almost all of the cost of these two operations is for labor.

Using a high-pressure water source would raise the effectiveness somewhat. If high-pressure water mains are located in the area being treated, then the necessary equipment will be no more extensive than several lengths of fire hose, a nozzle, and a ladder. Hosing would be done with two- or three-man

TABLE 2.4.1.11.1. Summary of Representative Cost and Productivity Data for Asphalt Road Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Vacuum	8,632	0.0043	0.0021	0.0022	
Low-pressure water	25,958	0.0013	0.0007	0.0006	
High-pressure water	2,685	0.0175	0.0074	0.0102	
Very high-pressure water	2,685	0.0206	0.0074	0.0132	
Foam	17,186	0.0911	0.0044	0.0040	0.0827
Strippable coating	4,297	1.7829	0.0094	0.0035	1.77
Planing	750	0.91	0.35	0.56	
Tack coat	12,890	0.3055	0.0035	0.0024	0.2996
Sealer	1,933	0.54	0.07	0.05	0.42
Road oil	12,890	0.3258	0.0077	0.0081	0.31
Pave with 1-inch asphalt	2,837	2.02	0.11	0.10	1.81
Resurface	2,837	2.93	0.46	0.66	1.81
Pave with 3-inch asphalt	946	6.06	0.33	0.30	5.43
Remove and replace	71	15.40	2.68	3.32	9.40

TABLE 2.4.1.11.2. Summary of Representative Cost and Productivity Data for Concrete Road Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Vacuum	8,632	0.0043	0.0021	0.0022	
Low-pressure water	25,958	0.0013	0.0007	0.0006	
High-pressure water	2,685	0.0175	0.0074	0.0102	
Very high-pressure water	2,685	0.0206	0.0074	0.0132	
Foam	17,186	0.0911	0.0044	0.0040	0.0827
Strippable coating	4,297	1.7829	0.0094	0.0035	1.77
Planing	625	1.09	0.42	0.67	
Tack coat	12,890	0.3055	0.0035	0.0024	0.2996
Sealer	1,933	0.54	0.07	0.05	0.42
Road oil	12,890	0.3258	0.0077	0.0081	0.31
Pave with 2-inch asphalt	1,419	4.04	0.22	0.20	3.62
Resurface	1,419	5.13	0.64	0.87	3.62
Pave with 3-inch asphalt	946	6.06	0.33	0.30	5.43
Remove and replace	171	19.62	2.48	3.77	13.37

TABLE 2.4.1.11.3. Summary of Representative Cost and Productivity Data for Other Asphalt Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2)			
		Total	Labor	Equipment	Material
Vacuum	4,316	0.0086	0.0042	0.0044	
Low-pressure water	12,979	0.0026	0.0014	0.0012	
High-pressure water	1,342	0.0350	0.0148	0.0204	
Very high-pressure water	1,342	0.0412	0.0148	0.0264	
Foam	8,593	0.0995	0.0088	0.0080	0.0827
Strippable coating	2,148	1.7978	0.0188	0.0070	1.772
Planing	375	1.82	0.70	1.12	
Tack coat	384	0.46	0.16		0.30
Sealer	91	1.04	0.41	0.12	0.51
Road oil	6,445	0.3416	0.0154	0.0162	0.31
Pave with 1-inch asphalt	1,418	2.23	0.22	0.20	1.81
Resurface	1,418	4.05	0.92	1.32	1.81
Pave with 3-inch asphalt	473	6.69	0.66	0.60	5.43
Remove and replace	35	21.40	5.36	6.64	9.40

TABLE 2.4.1.11.4. Summary of Representative Cost and Productivity Data for Other Concrete Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 $\$/m^2$)			
		Total	Labor	Equipment	Material
Vacuum	4,316	0.0086	0.0042	0.0044	
Low-pressure water	12,979	0.0026	0.0014	0.0012	
High-pressure water	1,342	0.0350	0.0148	0.0204	
Very high-pressure water	1,342	0.0412	0.0148	0.0264	
Foam	8,593	0.0995	0.0088	0.0080	0.0827
Strippable coating	2,148	1.7978	0.0188	0.0070	1.772
Planing	312	2.18	0.84	1.34	
Tack coat	384	0.46	0.16		0.30
Sealer	91	1.04	0.41	0.12	0.51
Road oil	6,445	0.3416	0.0154	0.0162	0.31
Pave with 2-inch asphalt	709	4.46	0.44	0.40	3.62
Resurface	873	11.99	2.10	6.28	3.61
Pave with 3-inch asphalt	75	8.54	2.10	1.18	5.26
Remove and replace	85	25.87	4.96	7.54	13.37

TABLE 2.4.2.1. Summary of Representative Cost and Productivity Data for Roof Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2)			
		Total	Labor	Equipment	Materials
Vacuum	81	0.23	0.21	0.02	---
Low-Pressure Water	81	0.23	0.22	0.01	---
High-Pressure Water	81	0.74	0.72	0.02	---
Wet Sandblast	21	4.84	2.11	2.73	---
Fixative	81	1.22	0.43	0.56	0.23
Foam	81	1.73	0.86	0.79	0.08
Strippable Coating	81	3.26	0.90	0.59	1.77
Remove and Replace	24	19.08	12.95	0.43	5.70

crews and most of the cost would still be for labor. However, in the event that a pumper truck is necessary to generate the required water pressure, the cost of the procedure would rise from about \$0.74 to \$2.34 per square meter, and labor's share of the input cost would fall sharply.

Sandblasting can be done either wet or dry. Both methods, however, pose serious potential for recontamination of adjacent surfaces, as well as those just treated. Dry blasting generates much airborne dust, while wet blasting can spread the contamination via the water waste. There is a technique called vacuum blasting in which the dry blast is combined with a vacuum intake which surrounds the blast nozzle. The result is that dust and sand do not escape from the area being blasted to recontaminate other areas. However, the coverage with this apparatus is so slow that this method becomes prohibitively expensive.

At \$4.30 per square meter for dry blasting without dust control, and \$4.84 per square meter for wet blasting without water treatment, these operations are sufficiently costly that they are likely to be used only in special situations. Wet blasting would be appropriate where water could be allowed to either absorb into the soil or run into the storm drains. Working from the top down on a roof with a good slope, it is estimated that this method can achieve a removal efficiency of 99 percent if the surface has not been rained on and about 97 percent if it has been rained on.

Application of a fixative to prevent resuspension could be done in much the same manner that other materials such as foam or strippable coating are applied. An appropriate choice of fixative in this use might be Compound SP-301. This will form a thin latex coating over the surface. Once cured, this material can be removed, but to do so requires use of a solvent. This operation would be particularly advantageous when used in conjunction with other operations such as removal and replacement.

Acidic foam can be used on roofs to draw contaminants out of surface cracks and irregularities. This material could be applied using the type of spray truck used for commercial lawn and tree spraying. To remove the foam, a long extension to the standard hose intake of a mobile vacuum sweeper would be used. The cost of this operation comes to around $1.54 per square meter.

Strippable coating could be applied to roofs in much the same way as the foam, except that a non-aerosal spray would be used. Again, a mobile spray truck would be the basic piece of equipment. Removal, however, would be largely a manual operation, with a worker pulling off pieces of the coating for later pickup. Despite the considerable labor time involved for this operation, about 56 percent of the $3.37 per square meter cost would be for the coating material itself. In addition to achieving an estimated 75 percent removal efficiency if accomplished before rain, a strippable coating would act as an effective fixative.

The most effective and the most costly operation for decontaminating roofs is simply to remove and replace them. To assure that the radioactive particles on the roof surface are in fact removed and not scattered over surrounding surfaces, actual removal should be preceded by coating the roof with road oil to fix the particulates to the roof. Roof removal and relacement are steps for which there is some established experience-based cost data available. Of course, the cost of removal, and especially replacement, depend in large part on the type of material used. For five-ply, built-up tar and gravel construction, the total cost is estimated at $18.51 per square meter. For asphalt strip shingles, the cost would be less, and for cedar shingles the cost would be more. If done before rain, removal and replacement is estimated to have near total effectiveness--99.9 percent. The effect of the rain, however, would be to move some of the radiation off of the roof and on to other surfaces which would not be directly affected by replacement of the roof. Thus, following rain, the estimated effectiveness of roof replacement would fall to 98%.

2.4.3 Lawns

Table 2.4.3.1 summarizes the data for lawn decontamination operations. Vacuuming is one of the simplest methods for decontaminating lawns. Using an extension hose to a standard vacuumized street sweeper, this method is estimated to achieve about 30 percent removal efficiency for lawns not rained on, and the cost would be around $0.19 per square meter. Rain is likely to render this method much less effective.

TABLE 2.4.3.1. Summary of Representative Cost and Productivity Data for Lawn Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 $/m^2) Total	Labor	Equipment	Materials
Vacuum	326	0.19	0.13	0.06	---
Water	1,302	0.014	0.013	0.001	---
Leaching	6,400	0.07	0.022	0.022	0.026
Close Mowing	150	0.147	0.129	0.017	---
Fixative	3,545	0.365	0.017	0.038	0.31
Remove and Replace	90	4.50	1.67	1.11	1.72

Driving radioactive particulates below the soil surface may, however, be an attractive strategy if the subsurface geology is such that the radiation will not cause problems by contaminating important water sources or by migrating to other undesirable locations. A straightforward watering of lawn surfaces could achieve a "removal" effectiveness of about 85 percent and would cost only about $0.015 per square meter. The effectiveness of this process could be accelerated by using one of a number of chemical agents that have the ability to solubilize radioactive fallout. Such chemicals include ferric chloride, EDTA, and calcium chloride. An application of 0.3-inch coverage of a ten percent solution of ferric chloride will remove about 85 percent of the radiation from the surface and cost about $0.33 per square meter. Of this, about $0.25, or 76 percent of the cost, would be for the ferric chloride.

Another lawn surface decontamination operation involves close mowing with bagging and removal of cuttings. This fairly simple method is estimated to achieve an effectiveness of 65 percent at a cost of about $0.16 per square meter.

Application of a fixative would improve the effectiveness of operations involving removal, such as close mowing and lawn removal and replacement. The nature of lawns makes fixing difficult, and it may be necessary to use a messy material such as road oil to achieve an effective application. The cost of road oil was used in estimating the cost of this operation; however, some other fixative could also be used. Road oil is somewhat more costly than most other fixatives.

As with pavement and roofs, the most effective and most costly decontamination operation of lawn surfaces is removal and replacement. Including application of a coating of road oil as a fixative, this procedure will cost about $4.50 per square meter. The removal efficiency is estimated at around 98 percent.

2.4.4 Agricultural Fields

Techniques for decontaminating agricultural fields include a variety of excavation, farming, and other procedures. One of the simplest and least costly procedures is to apply water to drive the contaminants into the soil. This is appropriate only where doing so is not likely to seriously damage underground water supplies. Also, this operation could drive the contaminants down to root level and increase the uptake into the plants, thereby magnifying the health hazard through ingestion. Where flood or sprinkler irrigation systems are present, this operation is easily accomplished. However, since many fields--especially those for raising grain--are not irrigated, the cost of applying water was based on using a tank truck with spreader or spray capability.

There are a variety of fixatives appropriate for use on soil. Section A.7.1 in Appendix A provides a general discussion of fixatives and their characteristics. For use on agricultural fields, this report assumes application of Coherex or a similar product. This would be applied using a tank truck with spray application ability.

Using a leaching agent such as ferric chloride or EDTA will enhance the ability of water to drive the radioactive materials into the soil. Again, however, consideration must be given to water supplies and crop uptake.

Scraping involves removing the top surface of soil. This would generally follow application of a fixative or water to minimize resuspension of radioactive particles during process of scraping. This operation would be done using standard earthmoving equipment such as front-end loaders. Hauling away of scraped soil would be done by dump trucks. The cost of hauling is handled separately throughout this report since the cost of this activity depends on the distance the material is to be hauled. It should be noted, however, that hauling any great distance significantly increases the cost of the operation.

In their study of decontamination techniques and efficiencies, Dick and Baker (1961) found plowing to be very effective in terms of the inhalation exposure pathway. Plowing works by moving the radioactive materials down into the soil. This standard farming operation has the lowest cost of any decontamination technique for agricultural fields. The reason for this low cost is the ability of mechanized farm equipment to treat large areas rapidly. Further, cost estimates were based on standard farm labor costs, which are substantially less than labor costs in construction and trade activities.

While plowing mixes the soil up to 10 or 12 inches deep, special equipment exists enabling much greater penetration of the contaminants into the soil. Deep plowing has the potential to mix or turn soil to a depth of 36 inches or more. One source reported the ability to plow to a depth of five feet through very hard soil. Because the coverage rate for this operation is relatively high, the cost per square meter is relatively low--$0.06--even though the operation requires a considerable amount of heavy equipment.

Clearing involves removing a standing crop from a field. This may be done to facilitate other operations such as fixative application or scraping; or clearing may be done primarily as a means of removing much of the contamination adhering to the crop itself. Clearing is most useful when the volume of the crop is great. This suggests that equipment intended to harvest or otherwise treat the crop may afford the best means for clearing. The cost estimate here is based on using a swather to remove a corn crop.

Covering the ground with six inches of uncontaminated soil may be done alone or in conjunction with scraping. In any case, covering provides both shielding and protection against inhalation.

The costs and rates of these operations are summarized in Table 2.4.4.1.

TABLE 2.4.4.1. Summary of Representative Cost and Productivity Data for Agricultural Fields Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Water	2,149	0.0219	0.0092	0.0127	
Fixative, Coherex	2,922	0.2061	0.0068	0.0094	0.19
Leach, $FeCl_3$	1,814	0.052	0.0109	0.0151	0.026
Scrape	875	0.31	0.13	0.18	
Plow 10-12 inches	8,500	0.004	0.001	0.002	
Deep plow	5,000	0.06	0.005	0.055	
Clear	543	0.026	0.009	0.017	
Cover with soil	549	0.371	0.106	0.265	

2.4.5 Orchards

Many of the operations for treating agricultural fields, wooded areas, or vacant land can also be used for treating orchards. Orchards, however, pose some unique problems for decontamination. First, the contamination will not only be distributed over the ground but also in the tree foliage and on the branches and trunks. Thus, an operation that decontaminates the ground will only be partially effective in decontaminating the entire orchard. Second, the trees are valuable and the intent to avoid damage to the trees will often impair the speed, effectiveness, and choice of decontamination operations. The trees limit what equipment can be used, the size of the equipment, and the maneuverability of the equipment.

The cost of low-pressure water is estimated on the assumption that flood irrigation is available. Application of fixative is considered from two perspectives. Aerial application would treat primarily tree foliage but would also tend to go to those surfaces that were most contaminated. In addition, the ground application of fixative to trees and to the ground was also considered. Ground application to the trees would be done with an orchard blast sprayer. A weed sprayer could be used to apply fixative to the ground.

Defoliation might be done to remove tree leaves and the contamination thereon. This procedure is accomplished by aerial spraying.

Soil scraping without removing the trees would employ two workers with shovels to remove dirt from the base of the trees. A small front-end loader would scrape, remove, transport the soil, and load it into dump trucks. This procedure requires extra care not to damage the trees or roots.

Shallow plowing or discing will help the contamination migrate down into the soil. Care must be taken with this activity to avoid root damage.

The most extensive and costly operation is removal and replacement of the trees. This would probably be done with fixing and soil scraping as well. The cost of scraping and the cost of covering with clean soil were estimated for two cases: with trees present and with trees removed.

In addition to defoliation, a significant proportion of the radioactive particles on the trees could be removed through radical pruning. This involves cutting back the branches to the maximum extent possible without killing the trees. This would, however, result in lowered property values because several years of crops would be lost. Operations on orchards are summarized in Table 2.4.5.1.

TABLE 2.4.5.1. Summary of Representative Cost and Productivity Data for Decontamination Operations on Orchards

Operation	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Water	3,541	0.0014	0.0014		
Fixative, aerial application	7,467	0.371	0.019	0.262	0.090
Fixative, ground application to trees and ground	280	0.213	0.027	0.047	0.10
Defoliate	8,331	0.0146	0.0006	0.0015	0.0105
Leach, $FeCl_3$	2,545	0.0338	0.0034	0.0030	0.026
Scrape without removing trees	148	0.658	0.496	0.162	
Plow	8,047	0.0044	0.0006	0.0018	
Remove and replace	98	1.185	0.355	0.595	0.236
Radical prune	340	0.071	0.029	0.042	
Cover with soil, trees removed	549	0.371	0.106	0.265	
Cover with soil, trees not removed	55	1.94	1.38	0.56	
Scrape with trees removed	875	0.31	0.13	0.18	

2.4.6 Vacant Land

Vacant land refers to undeveloped land with grass and brush plant cover. Operations for treating this land type are in most cases similar to operations for treating agricultural fields.

Fixative would be applied to vacant land using a spray distrubutor tank truck. Coherex or lignosite appear to be appropriate fixative choices. The costs reported here reflect those of Coherex.

Clearing involves no major equipment. This is done primarily by hand, though the laborer would be equipped with a power brush saw.

Scraping, watering, leaching, plowing, deep plowing, and covering with clean soil are all essentially the same operations as those described for agricultural fields. Note, however, that terrain and soil conditions may greatly affect the cost, rates, and even the ability to accomplish these operations at all. Table 2.4.6.1 summarizes the data for these operations.

TABLE 2.4.6.1. Summary of Representative Cost and Productivity Data for Vacant Land Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Fixative	2,192	0.2115	0.0090	0.0125	0.19
Clear	52	0.51	0.34	0.17	
Scrape	656	0.41	0.18	0.23	
Water	1,951	0.024	0.010	0.014	
Leach	1,171	0.066	0.017	0.023	0.026
Plow	1,770	0.028	0.007	0.015	
Deep plow	4,000	0.10	0.006	0.094	
Cover	549	0.371	0.106	0.265	

2.4.7 Wooded Land

Wooded land has the pervasive obstacle of difficult access. Application of lignosite fixative as indicated here is based on aerial application. Even with clearing, access to the area would be mostly restricted to foot traffic because of the remaining stumps. The mechanized scraping operation here includes grubbing prior to soil removal with front-end loaders. Grubbing is a term referring to removal of stumps.

If the trees or stumps are not removed, then scraping would be done manually with laborers equipped with shovels and wheelbarrows. This would be a very costly endeavor. It would only be appropriate where a large premium is placed on saving the trees. Similarly, manual means would be necessary to cover the ground with clean soil if the trees had not been removed. Operations in wooded areas are summarized in Table 2.4.7.1.

TABLE 2.4.7.1. Summary of Representative Cost and Productivity Data for Wooded Land Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 $/$m^2$)			
		Total	Labor	Equipment	Material
Fixative, aerial	5,600	0.49	0.025	0.350	0.120
Defoliate	5,554	0.0220	0.0009	0.0023	0.0158
Clear	266	0.802	0.469	0.33	
Grub and scrape	656	0.59	0.23	0.36	
Hand scrape	4	4.61	4.36	0.25	
Cover, cleared land	549	0.371	0.106	0.265	
Cover by hand	6	3.24	2.95	0.29	

2.4.8 Exterior Walls

This report considers two types of exterior walls, painted wood and brick. The former surface is characteristic of residential structures, while the latter is characteristic of commercial structures. Except for construction-type operations, such as removing and replacing the walls, treatment operations are identical for the two surfaces with respect to costs and rates of coverage. However, decontamination efficiencies for the two are not the same. In general, the greater roughness and porosity of brick make decontamination less effective.

A simple method of decontamination is to hose the surface with water. This water wash method costs only about $0.09 per square meter, requires no special equipment or labor skills, and is relatively fast compared with other operations. There is, however, the problem of contaminated water.

Washing and scrubbing will result in good removal through the abrasive action of scrubbing. These cost estimates are based on information supplied by commercial cleaning companies.

Fixatives are best applied with paint spray equipment. Here we assume application of Compound SP-301.

Vacuuming has the particular advantage of creating no byproduct of contaminated water. In addition, at $0.27 per square meter, the operation is relatively inexpensive.

Hydroblasting involves shooting an extremely high-pressure water jet at the surface. Equipment is available that would cut into or through the wall, so some care must be taken in selecting the proper water pressure. This operation is provided on a contract basis. Some of this equipment has the added advantage of using very little water. What water is used can be picked up with a wet vacuum.

Medium-pressure water scouring can be accomplished with a portable pump. This equipment is often used for removal of old paint.

Removal and replacement of walls require skilled craftsmen and extensive materials and is therefore quite costly. These operations are appropriate only where contamination is severe. Where contamination is so severe that the structure cannot be economically decontaminated, removal of the entire structure may be necessary. The costs here are expressed in terms of exterior wall area. This is based on estimated representative structure dimensions as incorporated in Subroutine XFORM, described in Appendix E.

Both foam and strippable coating would be applied with paint spray equipment. Foam would be removed by vacuuming, and the strippable coating would be removed by hand.

The costs and rates for these operations are summarized in Table 2.4.8.1 and Table 2.4.8.2.

TABLE 2.4.8.1. Summary of Representative Cost and Productivity Data for Decontamination Operations on Exterior Wood Walls

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Water wash	203	0.091	0.086	0.005	
Wash and scrub	10	1.75	1.15	0.60	
Fixative	40	0.834	0.555	0.049	0.23
Vacuum	69	0.27	0.16	0.11	
Hydroblast	11	8.50	3.39	5.11	
Medium-pressure water	8	2.43	2.18	0.25	
Remove, replace, paint	7.6	24.35	18.33	0.23	5.79
Remove structure	4.4	13.87	13.87		
Foam	40	0.96	0.72	0.16	0.08
Strippable coating	40	2.92	1.09	0.06	1.77

TABLE 2.4.8.2. Summary of Representative Cost and Productivity Data for Decontamination Operations on Exterior Brick Walls

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Water wash	203	0.091	0.086	0.005	
Wash and scrub	10	1.75	1.15	0.60	
Fixative	40	0.834	0.555	0.049	0.23
Vacuum	69	0.27	0.16	0.11	
Medium-pressure water	8	2.43	2.18	0.25	
Hydroblast	11	8.50	3.39	5.11	
Scarify	4	22.68	20.85	1.83	
Remove and replace	1.35	116.01	118.65	5.37	41.99
Remove structure	1.69	68.95	47.81	21.14	
Foam	40	0.96	0.72	0.16	0.08
Strippable coating	40	2.92	1.09	0.06	1.77

2.4.9 Interior Floor and Walls

Floor surfaces include linoleum, wood, carpeted, and concrete floors. Linoleum is considered representative of asphalt tile, vinyl, and other resilient floor coverings. Interior walls include painted wood, plaster walls and concrete walls. Most of the operations for these surfaces are similar or identical. The major differences are for the removal and replacement. Decontamination efficiencies, however, are not the same across surfaces. For example, vacuum removal of particles is much easier and more thorough on linoleum floors than on carpeted floors.

Most of the operations for treating interior surfaces have already been described above in discussions of decontamination techniques for other surfaces. Some operations require explanation, however. Sanding of wood floors refers to a thorough refinishing of the floor using an ordinary carpenter. For carpeted floors, scrubbing and washing is not appropriate. However, the costs of steam cleaning and carpet shampooing are listed. The costs and rates of the operations are summarized in the following tables.

TABLE 2.4.9.1. Summary of Representative Cost and Productivity Data for Decontamination Operations on Linoleum Floors

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Vacuum	69	0.27	0.16	0.11	
Scrub and wash	10	1.75	1.15	0.60	
Strippable coating	40	2.92	1.09	0.06	1.77
Foam	40	0.96	0.72	0.16	0.08
Fixative	40	0.83	0.05	0.23	
Remove and replace	5.48	14.47	8.11		6.36

TABLE 2.4.9.2. Summary of Representative Cost and Productivity Data for Decontamination Operations on Wood Floors

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Vacuum	69	0.27	0.16	0.11	
Scrub and wash	10	1.75	1.15	0.60	
Strippable coating	40	2.92	1.09	0.06	1.77
Foam	40	0.96	0.72	0.16	0.08
Sand	1.32	23.74	18.45		5.29
Fixative	40	0.83	0.56	0.05	0.23
Remove and replace	1.73	57.19	29.70		27.49

TABLE 2.4.9.3. Summary of Representative Cost and Productivity Data for Decontamination Operations on Carpeted Floors

Operation	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
Vacuum	69	0.27	0.16	0.11	
Foam	40	0.96	0.72	0.16	0.08
Fixative	40	0.83	0.56	0.05	0.23
Remove and replace	3.7	22.21	8.21		14.00
Steam clean	33	0.74	0.59	0.15	
Shampoo	40	1.25	0.80	0.45	

TABLE 2.4.9.4. Summary of Representative Cost and Productivity Data for Decontamination Operations on Concrete Floors

Operation	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
Vacuum	69	0.27	0.16	0.11	
Scrub and wash	10	1.75	1.15	0.60	
Strippable coating	40	2.92	1.09	0.06	1.77
Foam	40	0.96	0.72	0.16	0.08
Scarify	8.1	11.44	10.43	1.01	
Resurface	6	13.344	10.90	1.14	1.30
Medium-pressure water	8	2.43	2.18	0.25	
Hydroblast	11	8.5	3.39	5.11	
Scarify and resurface	6	24.78	21.33	2.15	1.30
Fixative	40	0.83	0.56	0.05	0.23

TABLE 2.4.9.5. Summary of Representative Cost and Productivity Data for Decontamination Operations on Painted Wood, Plaster Interior Walls

Operation	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
Vacuum	69	0.27	0.16	0.11	
Scrub and wash	10	1.75	1.15	0.60	
Strippable coating	40	2.92	1.09	0.06	1.77
Foam	40	0.96	0.72	0.16	0.08
Fixative	40	0.83	0.56	0.05	0.23
Remove and replace	5.28	23.84	21.15		2.69

TABLE 2.4.9.6. Summary of Representative Cost and Productivity Data for Decontamination Operations on Interior Concrete Walls

Operation	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Vacuum	69	0.27	0.16	0.11	
Scrub and wash	10	1.75	1.15	0.60	
Strippable coating	40	2.92	1.09	0.06	1.77
Foam	40	0.96	0.72	0.16	0.08
Fixative	40	0.83	0.56	0.05	0.23
Scarify	4	22.68	20.85	1.83	
Medium-pressure water	8	2.43	2.18	0.25	
Hydroblast	11	8.50	3.39	5.11	
Remove and replace	3.95	180.59	130.23	15.60	34.77

2.4.10 Automobiles

Automobiles are treated in a manner similar to the way property types and land areas are treated. Automobiles are comprised of four "surfaces": exteriors, interiors, tires, and engine and drive train. For each of these surfaces, different decontamination techniques are available. Their costs and rates have been estimated for this report. Unlike costs for other surfaces, costs here are not expressed in terms of dollars per square meter but instead are given as dollars per vehicle. Likewise, the rate is expressed in terms of vehicles per hour rather than square meters per hour.

The first set of operations consists of removing the vehicles to a site where they can be cleaned. The cost of these operations is included under automobile exteriors. While no efficiency is assigned, vehicle transport is a necessary precondition for decontamination. The alternatives for transporting cars are having someone drive the car to the decontamination site, having the car towed, or having the car hauled via a vehicle transport truck. Towing is the most costly, and driving the car is the least costly.

The operations for cleaning the car's exterior are ordinary spray wash, detailed cleaning and scrubbing, and sanding and repainting. The costs of these operations cover a wide range, and the least costly has a relatively high effectiveness in terms of decontamination.

The costs and rates of these operations are presented in Table 2.4.10.1

The options for decontaminating the interior are ordinary vacuuming; detailed vacuuming and cleaning; removing the interior, cleaning, and replacing; and re-upholstering. The costs and rates for these operations are shown in Table 2.4.10.2.

TABLE 2.4.10.1. Summary of Representative Cost and Productivity Data for Automobile Exterior Decontamination Operations

Operation	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Drive car	2	15.00	13.50	0.75	0.75
Tow car	1	50.00	20.00	25.00	5.00
Truck car	4	40.00	16.00	20.00	4.00
Ordinary wash	4	5.00	4.00	0.50	0.50
Detailed wash	0.25	75.00	58.50	7.50	9.00
Repaint	0.083	900.00	558.00	72.00	270.00

TABLE 2.4.10.2. Summary of Representative Cost and Productivity Data for Automobile Interior Decontamination Operations

Operation	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Ordinary vacuum	3	6.00	4.10	0.60	0.30
Detailed vacuum and clean	1	45.00	31.50	4.50	9.00
Remove, clean, and replace	0.125	300.00	240.00	30.00	30.00
Re-upholster	0.14	600.00	210.00	180.00	210.00

The operations for decontaminating tires are ordinary spray wash, detailed scrub and wash, sandblast, and remove and replace with new tires. The costs and rates for these operations are shown in Table 2.4.10.3.

TABLE 2.4.10.3. Summary of Representative Cost and Productivity Data for Automobile Tires Decontamination Operations

Operation	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Material
Ordinary spray wash	10	1.85	1.75	0.10	--
Detailed wash and scrub	3	5.83	3.83	2.00	--
Sandblast	8	12.71	5.54	7.17	--
Remove and replace	1	225.00	22.50	24.75	176.75

The operations for cleaning the automobile engine and drive train are steam cleaning and cleaning with an organic solvent. Table 2.4.10.4 summarizes the costs and rates for these operations.

TABLE 2.4.10.4. Summary of Representative Cost and Productivity Data for Decontamination Operations on Automobile Engines and Drive Trains

Operation	Rate (autos/hr)	Cost (1982 $/auto)			
		Total	Labor	Equipment	Material
Steam clean	1	26.00	18.72	2.60	4.68
Clean with solvent	1	37.00	35.15	0.35	1.40

2.4.11 Hauling

A number of operations require hauling. Many require hauling of soil, removed material, or byproducts to a dump site. These hauling costs are calculated separately and then added to the cost of the operation. Some operations require bulk hauling of materials to the decontamination site. The calculation of hauling costs depends first on the distance to the dump site. Second, since the focus of interest in this report is costs per unit area, hauling costs also depend on the volume of material to be hauled for each square meter of surface treated. For example, soil scraping generates about 1.15 cubic meters of material per square meter of ground. Table A.23.2 in Appendix A shows the volume of material per square meter to be hauled.

Table 2.4.11.1 shows the total cost to haul a cubic meter of material and the rate in terms of cubic meters per hour per dump truck for selected round-trip distances.

TABLE 2.4.11.1. Summary of Representative Cost and Productivity Data for Hauling

Round-Trip Distance (Miles)	Rate (m^3/hr/truck)	Cost (1982 $/$m^3$)
1	38.2	1.72
2	30.6	2.54
3	25.5	2.57
4	21.8	3.00
5	19.1	3.43
10	15.8	4.15
20	13.9	4.72
30	11.8	5.58
50	9.9	6.65
100	5.5	12.00

2.5 DECONTAMINATION EFFICIENCIES FOR VARIOUS SURFACES

This section gives estimates of removal efficiencies for decontamination operations. Actual efficiencies are highly variable, being subject to numerous factors. For this reason the efficiency estimates in this report should be regarded as relative measures of the expected effectiveness of the operations. When one operation follows another, the efficiency of the second operation will usually fall. This is mostly a result of the simple fact that the first operation will tend to remove those particles that are the easiest to remove. The derivation of efficiencies is explained in more detail in Appendix B.

There are few sources which give information about the efficiency of large surface area decontamination techniques. The best available data for this purpose come from field tests performed in the 1960's. However, specific data describing the actual decontamination operations used in these tests are not available. Thus, important information such as how much water was used for a high pressure water wash is unknown. Similarly, the concentration of leaching solutions was not provided.

A further difficulty lies in determining the removal efficiency of an operation when that operation follows another operation. Clearly, a low pressure water flushing of streets will be less effective, in terms of percent of contaminants removed, if it follows a treatment of strippable coating rather than if it was the first operation to be performed. Decontamination efficiencies for second, third, and fourth steps were judged on the basis of the relative efficiencies listed and on the assumed diminishing effectiveness of subsequent operations on the same surface as well as the likely interaction between different operations.

The most important point of this discussion is that the reader should be aware that the decontamination efficiencies are very approximate estimates. Their validity and potential usefulness lie in their mututal consistency. For this reason they should more properly be viewed as relative decontamination indices.

2.5.1 Cost and Efficiencies of Decontamination Methods

In the terminology used here, a sequence of "operations" comprises a "method". The cost of a method is equal to the sum of the costs of the constituent operations. The net efficiency of the method, however, is a more complex function of separate operations. (These net efficiencies are explained in more detail in Appendix B.) The assortment of efficiency-cost relationships of the several methods constitutes a choice menu for the planning of decontamination actions. These relationships are presented graphically in Figures 2.5.1 through 2.5.8. The graphic representation is facilitated by transforming efficiencies to decontamination factors. The relationship is

$$DF = \frac{100}{100-E}$$

where DF is the decontamination and E is the efficiency expressed as a percentage.

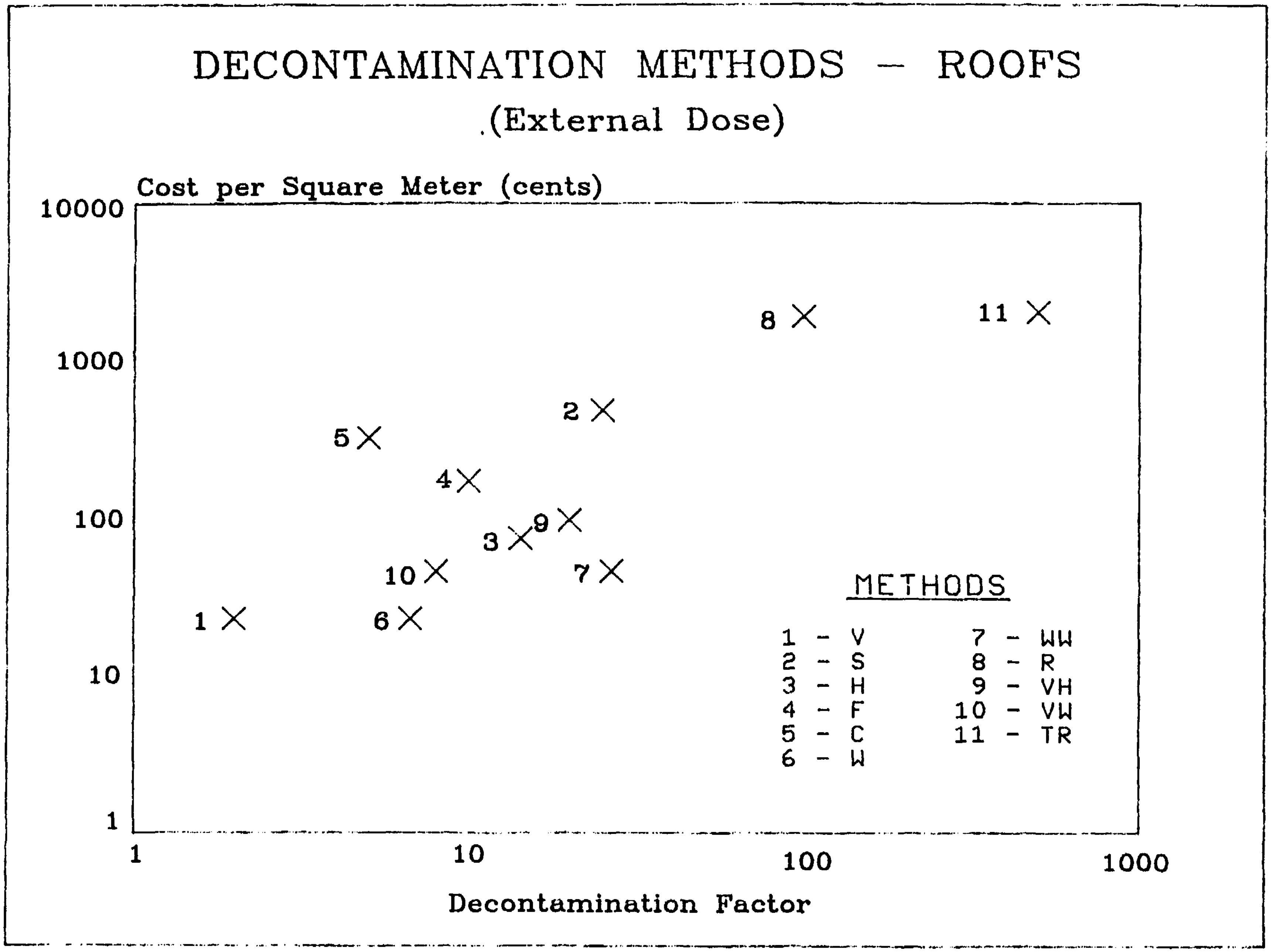

FIGURE 2.5.1. Decontamination Costs for Roofs, by Method and Decontamination Factor

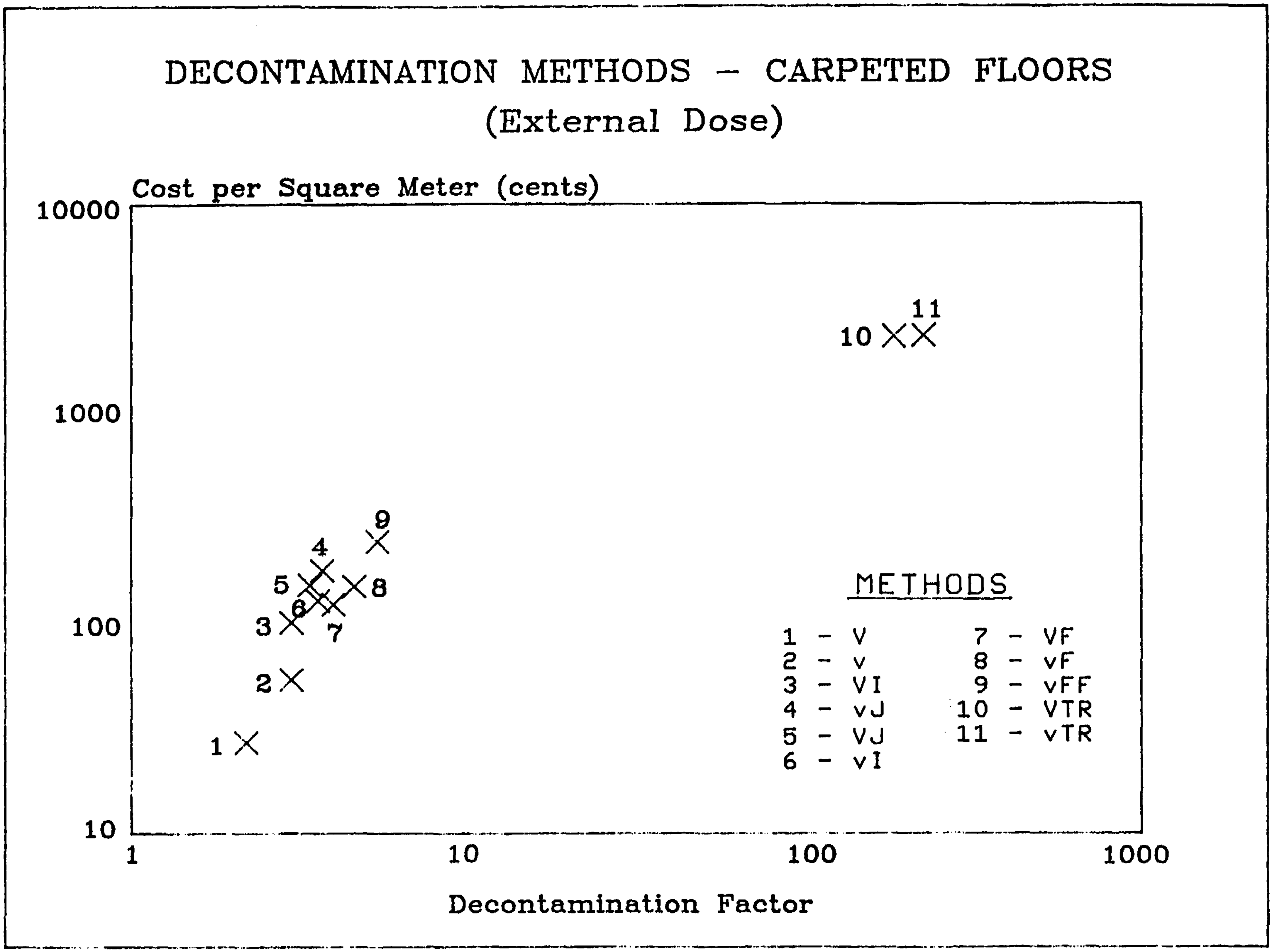

FIGURE 2.5.2. Decontamination Costs for Carpeted Floors, by Method and Decontamination Factor

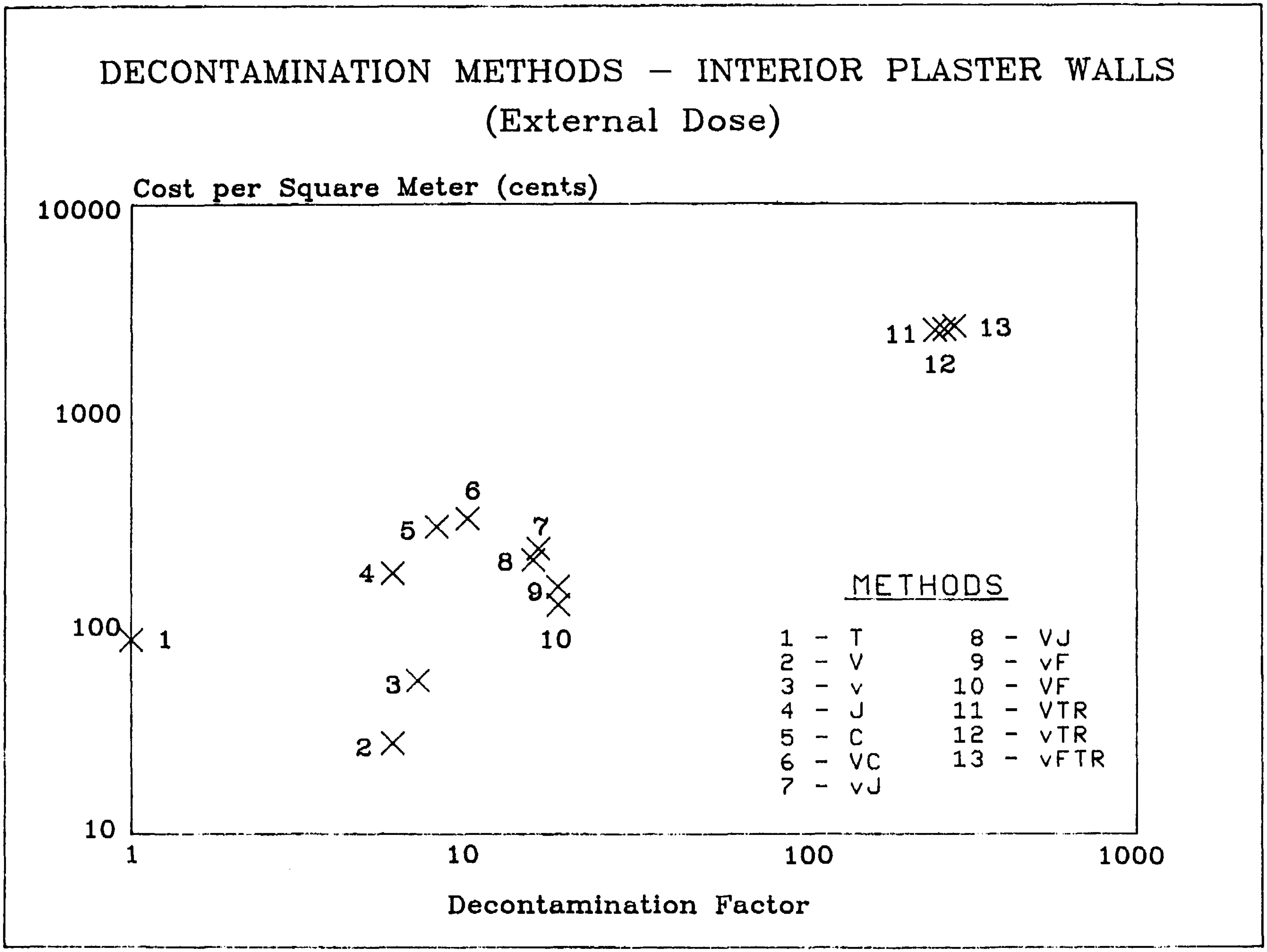

FIGURE 2.5.3. Decontamination Costs for Interior Plaster Walls, by Method and Decontamination Factor

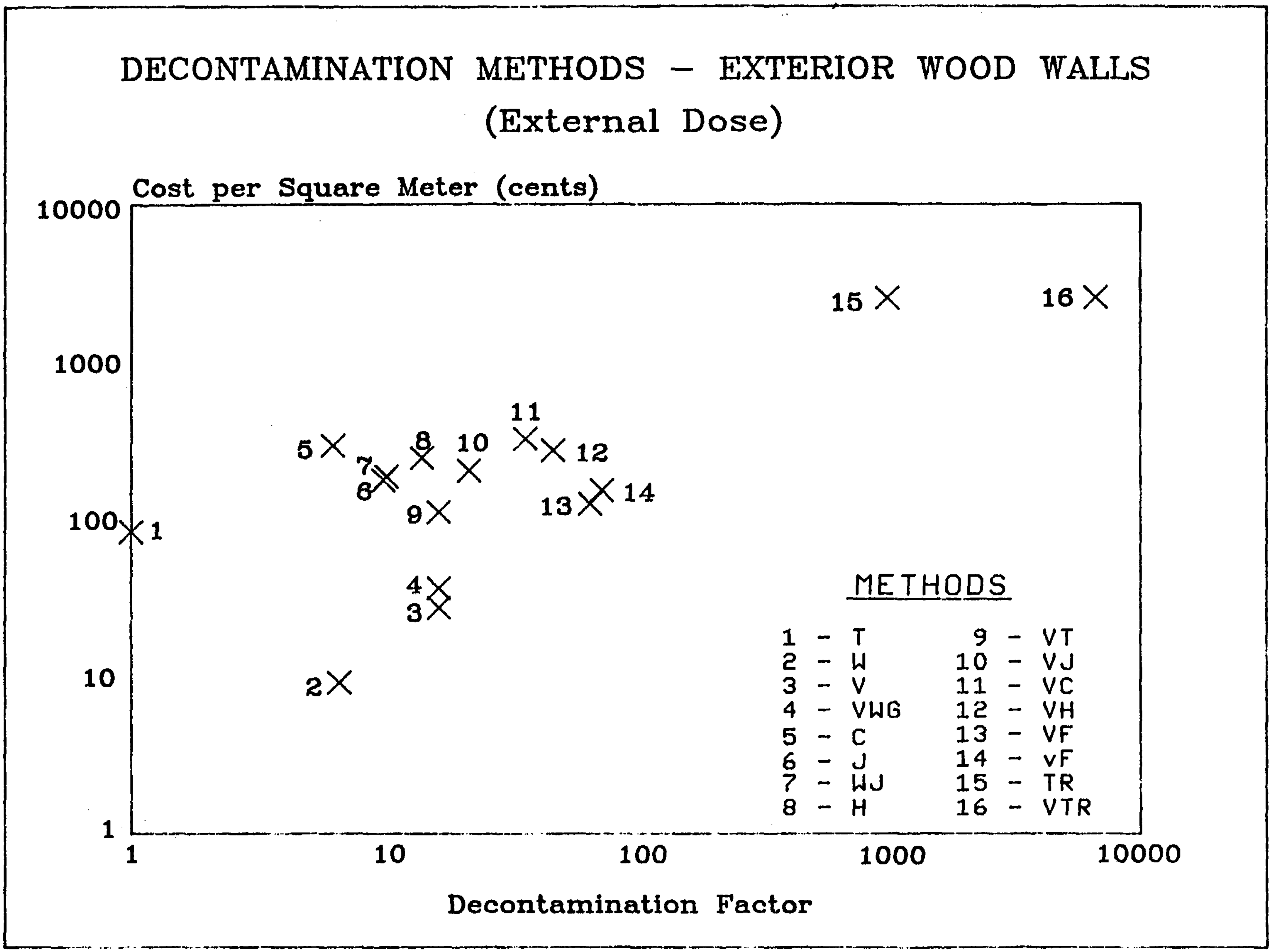

FIGURE 2.5.4. Decontamination Costs for Exterior Wood Walls, by Method and Decontamination Factor

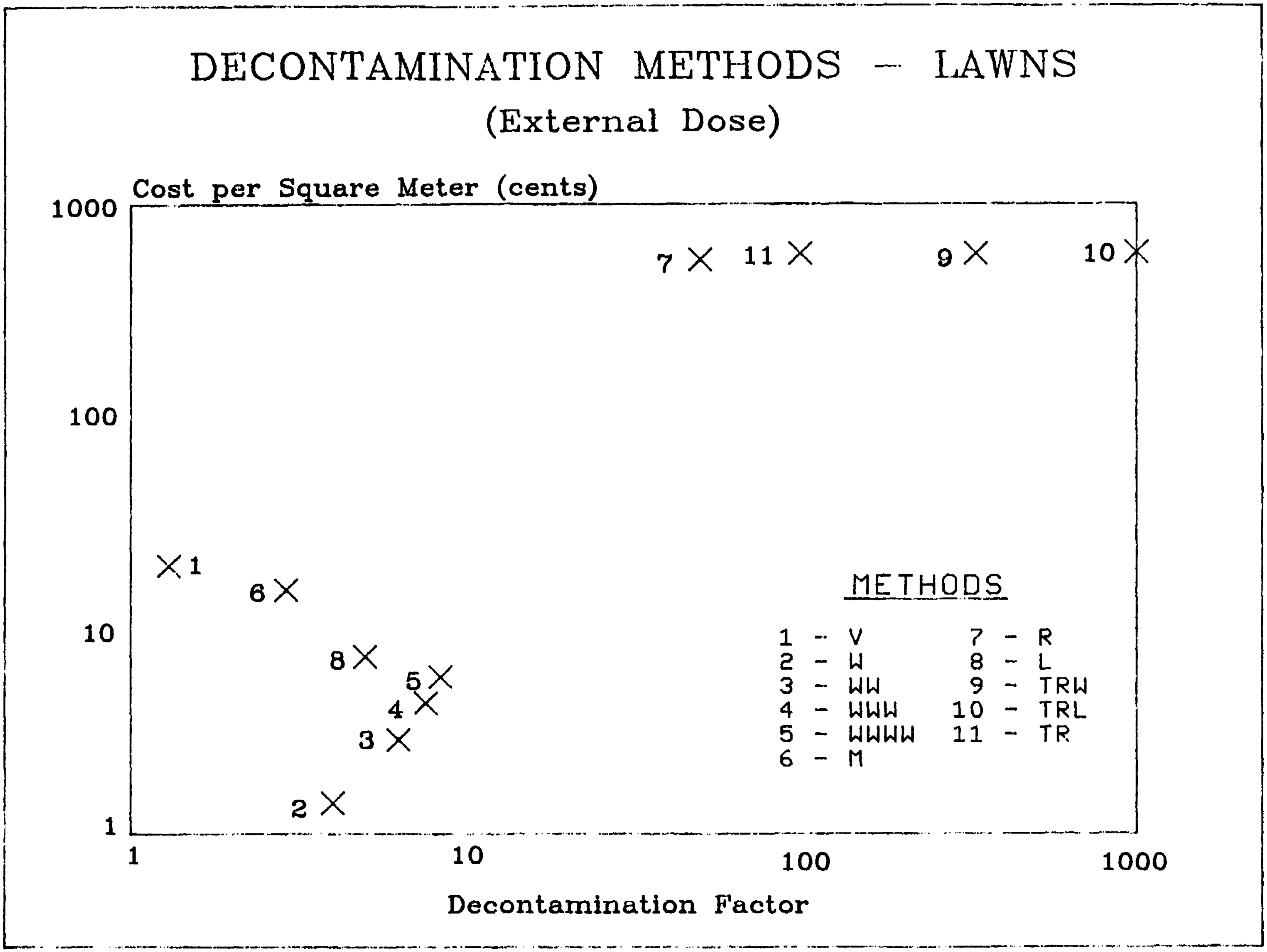

FIGURE 2.5.5. Decontamination Costs for Lawns, by Method and Decontamination Factor

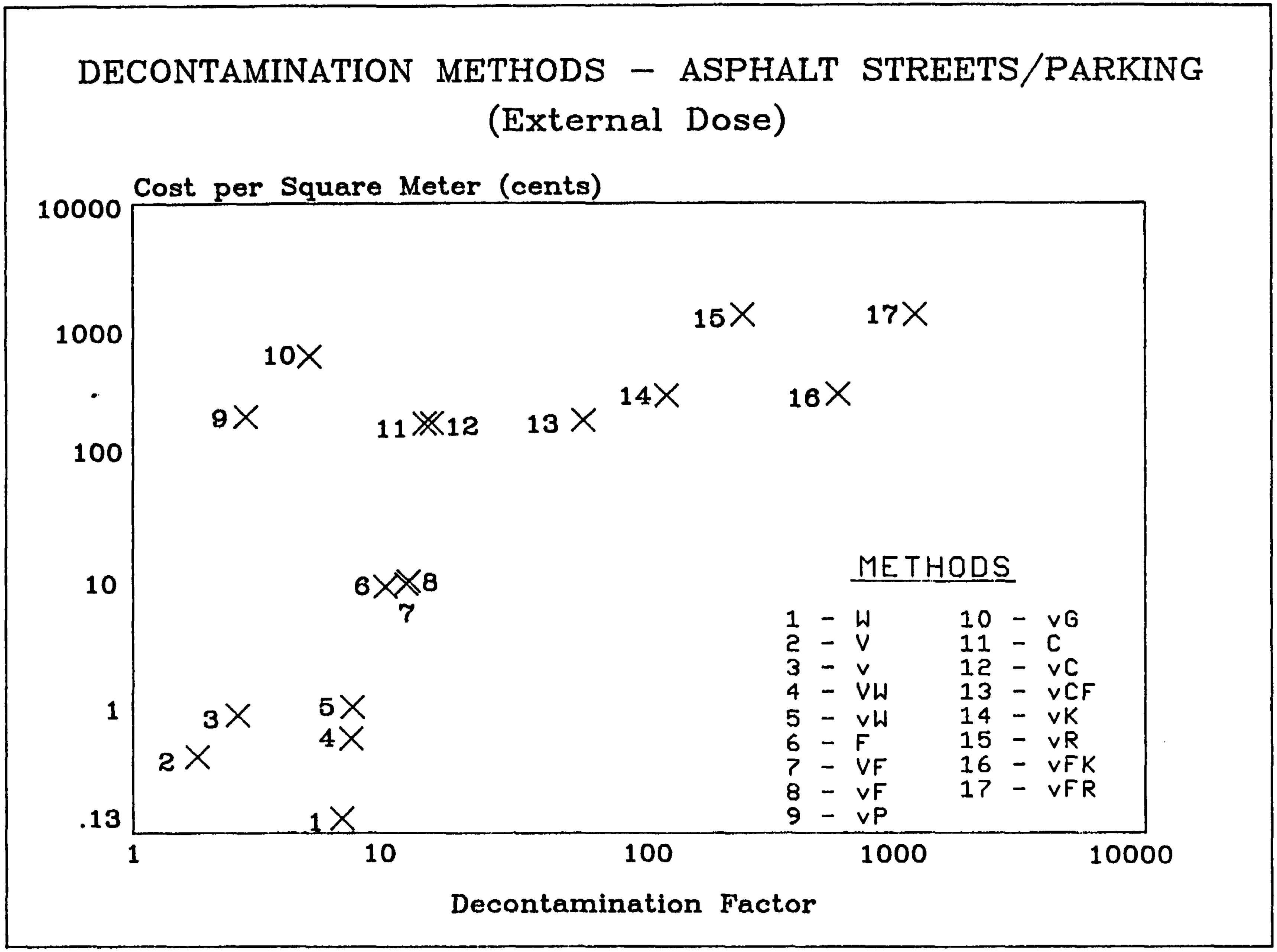

FIGURE 2.5.6. Decontamination Costs for Asphalt Streets/Parking, by Method and Decontamination Factor

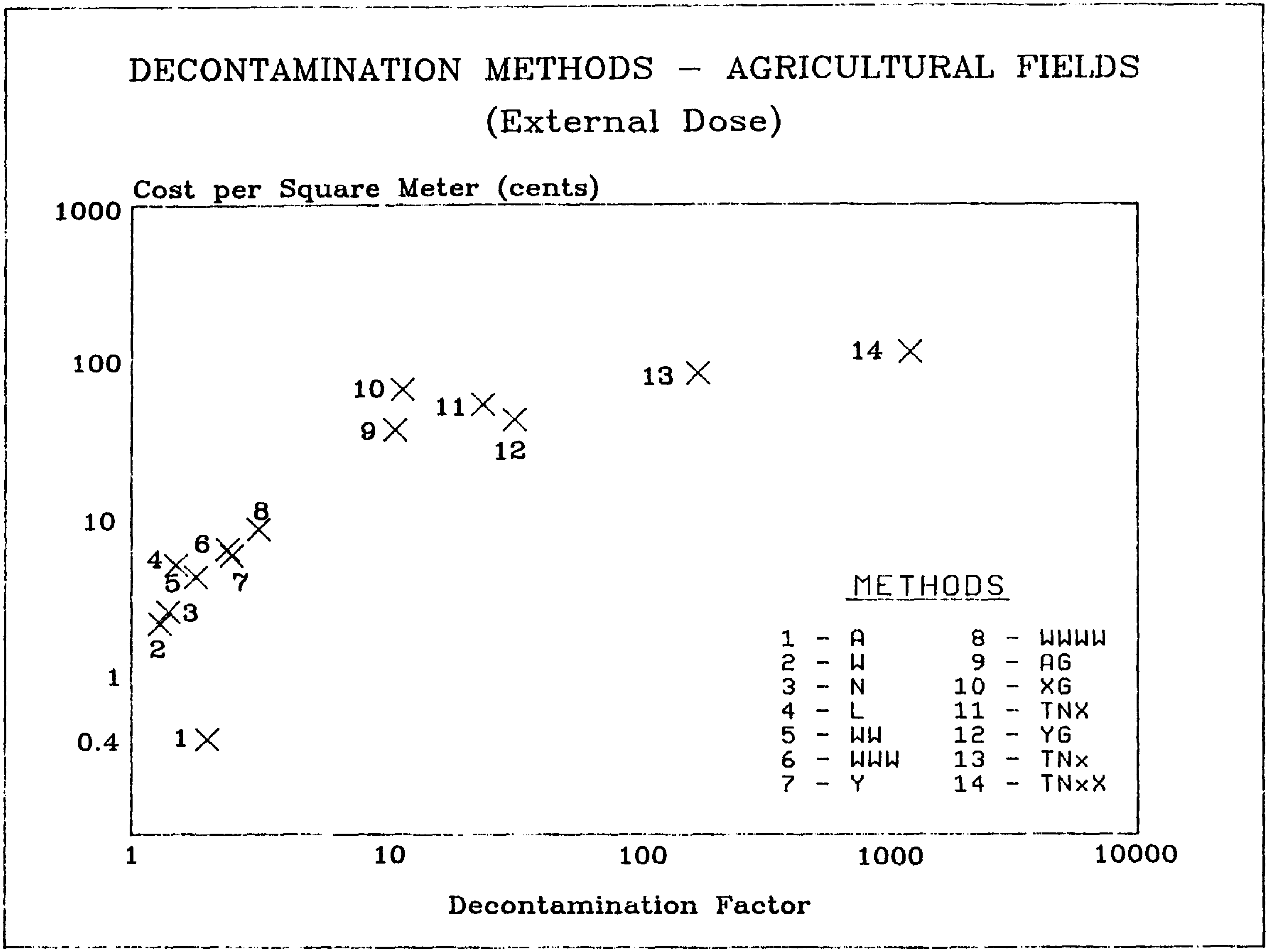

FIGURE 2.5.7. Decontamination Costs for Agricultural Fields, by Method and Decontamination Factor

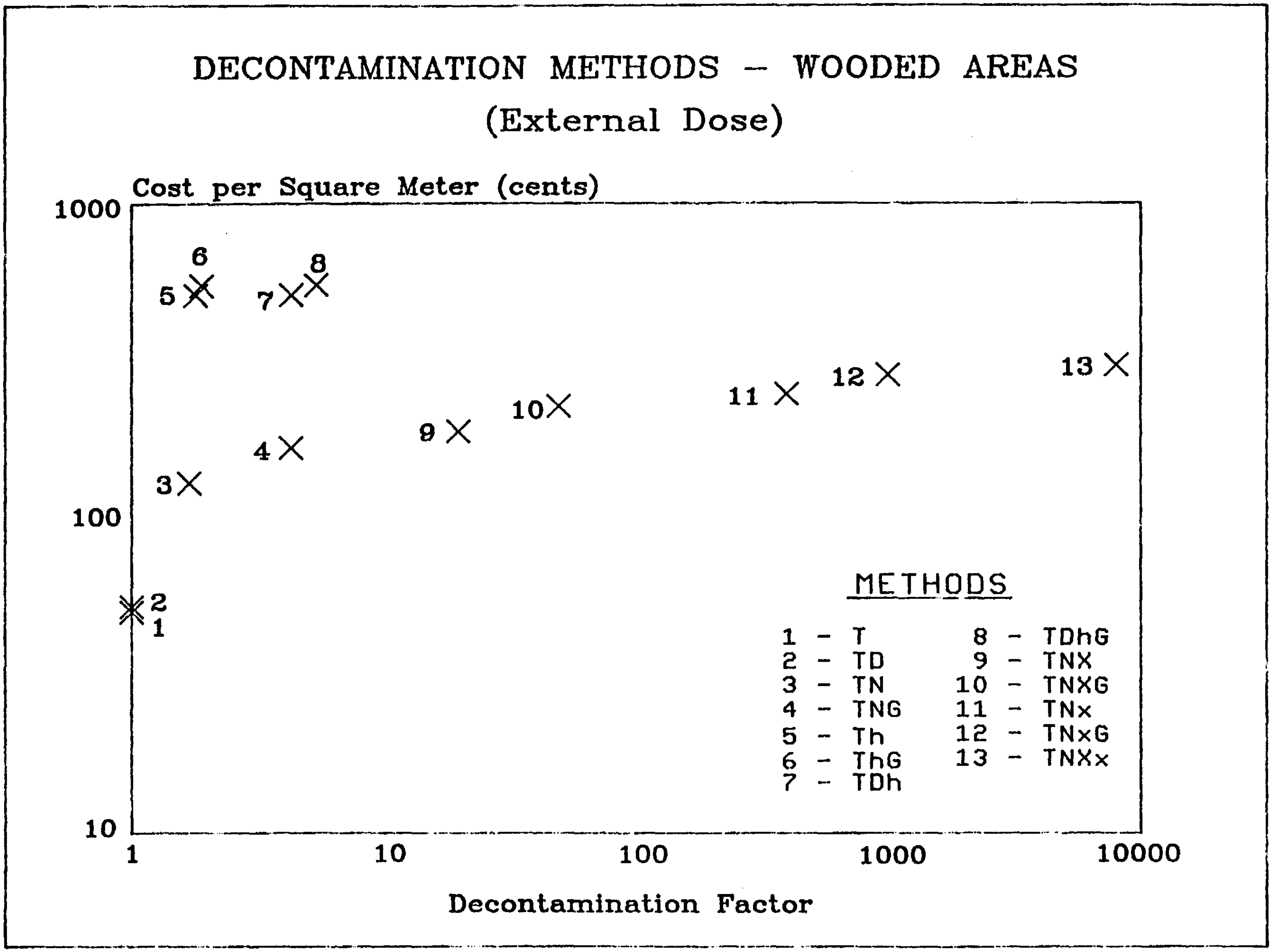

FIGURE 2.5.8. Decontamination Costs for Wooded Areas, by Method and Decontamination Factor

As an example consider Figure 2.5.1, which shows the decontamination factors and costs for several methods of decontaminating roofs. (The methods indicated in Figures 2.5.1 thru 2.5.8 use the code letters defined in Table 1.1, page 1.5.) Because the costs and decontamination factors cover such a broad range with relatively small differences for smaller values, a logarithmic scale is used in presenting the scattergram.

In general, one would like to obtain a high decontamination factor at low cost. This means that preferred choices are represented by those points which are toward the bottom and the right of the graph. Method 7--two applications of water (WW)--has a higher decontamination factor than methods 2, 3, 4, 5, 9 and 10, yet it is no more costly than any of these methods. In other words, it "dominates" these methods and will always be preferred in the absence of considerations other than cost and efficiency. In Figure 2.5.1, methods 6, 7, 8 and 11 dominate all of the other methods. In general, the set of points defining the dominant methods will tend to be shaped like the upper branch of a hyperbola, approaching 100 percent removal efficiency at extremely high costs. This general shape can be discerned for this entire set of figures.

In practice, some of the dominant methods will be excluded because their application would create additional problems and costs. For example, using water to decontaminate roofs could cause a contaminated water problem, requiring the water to be collected and treated. The additional costs to comply with these requirements could result in dominated methods being less costly and therefore preferred.

3.0 THE SITE DATA BASE

This chapter describes procedures for preparing the site database. The chapter begins with a discussion of the need to organize the radiologically contaminated area into a grid. This grid facilitates the analysis by dividing the area into many manageable parts. Three different types of grid are considered and the advantages and disadvantages associated with each are discussed. Section 3.2 describes the contents of the site database and considers various procedures for developing the data for it. The main elements of the site database include data on the type of property that has been contaminated, the degree of contamination, and the value of the affected property. The chapter concludes with a description of software programs that have been developed to assist in the preparation of the site database.

3.1 SELECTION OF THE GRID

To prepare the accident site for analysis, a first step is to partition the radiologically affected area into a grid. It is usually assumed that all exterior, horizontal surfaces within any grid element receive an equal quantity of contamination. While this assumption is not necessary, it does serve to simplify the analysis. The analyst may choose to utilize a 1) rectangular, 2) radial, or 3) irregular grid. Each has its advantages and disadvantages, as will be made clear in the discussion that follows.

3.1.1 Rectangular Grid

In a rectangular grid, all of the grid elements are of the same size and are rectangular in shape. Since data must be supplied for each of the grid elements, the size of the data acquisition effort can be adjusted by altering the size of the grid element. If radiological survey data are collected at locations that are spaced evenly apart, then a rectangular grid with a data point at the center of each grid element might best meet the assumption that contamination levels are constant over all horizontal, exterior surfaces within each grid element.

For any grid, land use data and information on property values need to be developed for each of the grid elements. This requirement could be particularly difficult to meet in the case of a rectangular grid. However, if population data are available for each of the grid elements, then a site data model that has been developed by PNL could be used. This microcomputer program is used with a radial or rectangular grid. Its use is illustrated in the case study described in Chapter 5, and its technical aspects are described in Appendix E. The program takes land use and property value information by political subdivision (such as township or county), and imputes land uses and property values to each grid element based on the grid element population counts.

In the absence of population counts for each grid element, one could simply assume that the population within each political subdivision is uniformly distributed geographically. This approach, however, could be improved through the use of topographical maps of the U.S. Geological Survey. The 7-1/2 minute series maps show individual house and business establishments. Unfortunately, small business establishments are not distinguishable from residences, and large multi-family establishments are indistinguishable from other large buildings. Nevertheless, knowing where the developed property is can be an aid in estimating the population within each grid element.

3.1.2 Radial Grid

Ground concentrations of contaminants near the point of release would be relatively heavy. Initially, these concentrations would fall off sharply, but as the plume travels downwind the decline would become much more gradual. For analyzing such a site, a radial grid is particularly well suited. Because it has smaller grid elements centered close to the accident site, it provides greater resolution where it is most needed. A radial grid is illustrated in Figure 3.1.

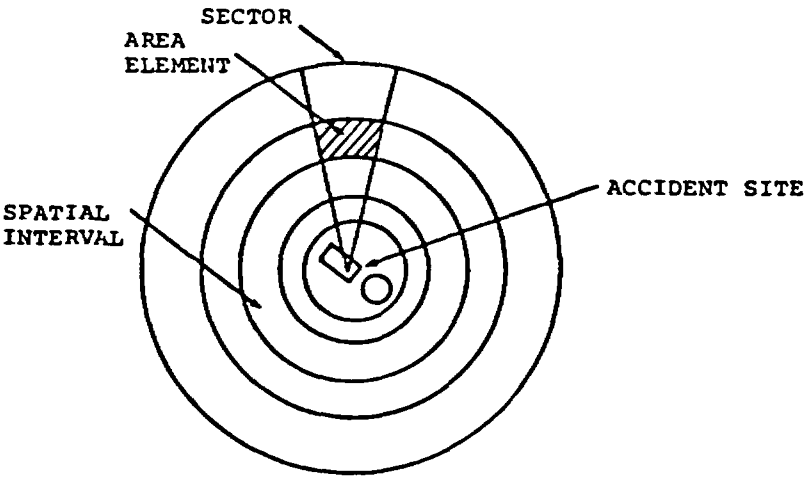

FIGURE 3.1. Typical Radial Grid Geometry

As noted earlier, the greatest disadvantage with a radial grid is obtaining population, land use and property value information for each of the grid elements. The major analytical tool used by the NRC to assess accident consequences around reactor sites is a computer model called CRAC2 (Calculations of Reactor Accident Consequences, Version 2). This model is based on a radial grid, but it is not often used with site-specific data because of the difficulty of getting information that conforms with the grid elements.

To make the radial grid a more attractive option, the PNL-developed software program mentioned in the previous section is directly applicable. This program uses actual population counts for the grid elements to increase the accuracy of imputing land uses and property values to each grid element. The population counts for this technique have been developed for the NRC by Oak Ridge National Laboratory and are available for the areas surrounding all existing reactor sites.

3.1.3 Irregular Grid Based on Political Subdivision Boundaries

A third alternative is to use existing political boundaries to define the grid. A major advantage with this approach is that data are often published or otherwise available for political subdivisions. Relatively good resolution can be obtained for the analysis if data are available at the township level. Good resolution is especially important close to the release point. If one needs to analyze a very severe accident, with significant contamination spread over hundreds or thousands of square miles, then as one goes beyond, say, 40 or 50 miles from the point of release, grid elements formed by county boundaries should prove adequate.

There are two potential disadvantages with the irregular grid. The first is that this type of grid will not likely provide as fine a resolution in areas immediately around the release point as will a radial grid. A possible solution to this is to use finer grid elements by partitioning the political subdivision(s) within a few miles of the release point. A U.S. Geological Survey 7.5 minute series map can be used to allocate population, land use and property values of the subdivision among these smaller grid elements. Unfortunately, however, many of these maps are not current.

The second potential disadvantage is determining the dose or ground concentration for each of the grid elements. To solve this problem, PNL has developed an interactive code for a microcomputer that will provide an estimate of the dose or ground concentration at any point that has a downwind component. The vector path of the plume and a line taken orthogonally from the point of interest to the vector path form two legs of a right triangle. If one enters the length of these two legs into the program, an estimated value for the dose at that point is returned.

3.2 CONTENTS OF THE SITE DATABASE

As already noted, the following information should be contained in the site database for each grid element:

- the extent to which the property has been contaminated
- the type of property that has been contaminated
- the value of the contaminated property.

3.2.1 Contamination Level

The site database must provide DECON with information on the severity of the contamination of exterior, horizontal surfaces. The information can be supplied in units of dose, dose commitment, ground concentration or other comparable unit, as long as the cleanup criterion is also specified in the same unit. DECON forms a ratio between the contamination measure and the cleanup criterion to obtain a target decontamination factor. The target decontamination factor is the factor by which contamination must be removed from the surface in order to meet the cleanup criterion. For example, if the ground concentration within a grid element gives an external 70-year dose commitment of 250 rem, a cleanup criterion of 10 rem results in a target decontamination factor of $250 \div 10 = 25$. To meet a cleanup standard of 10 rem, 25 parts of contaminant must be removed from the contaminated surface for every one part that is allowed to remain on it.

In developing a decontamination schedule that minimizes the site restoration costs and property losses resulting from the accident, DECON recognizes the effects of radioactive decay and weathering in reducing external dose. This information is transmitted to DECON as follows: Predicted ground concentrations, measured in curies per square meter, are calculated using the CRAC2 computer program. The ground concentrations are then used in a microcomputer program that implements the weathering and decay models from the Reactor Safety Study (USNRC 1975). These models estimate either 1) the external whole body dose rate measured at the end of each year following the accident; or 2) using CRAC2 dose conversion factors, total dose over some defined time period and measured at the end of each year following the accident. DECON makes direct use of this time series of doses or dose commitments.

3.2.2 Type of Property Contaminated

Different types of property, even if equally contaminated, will generally require different decontamination treatments. Indeed, in giving an overview of the methodology in Section 1.4, it was suggested that treatments be thought of as applying to surfaces. Unfortunately, information on the quantity of different surface types within geographical areas around reactor sites is not available. The kind of information that can usually be found, primarily from state and local agencies, relates to land use. Several land use designations are customarily defined and the acreage in each land use category is compiled. The step necessary to make this information usable for our purposes is to transform the land uses into their constituent surfaces.

The land uses currently implemented by DECON and its associated software are listed in Table 3.1. Comparing these land uses with the surfaces currently implemented (see Table 1.2) indicates that some land uses transform directly into surfaces. Wooded areas, orchards and vacant land fall into this category. The category "streets and roads" divides into two surfaces: asphalt and concrete streets and roads, while grain crop and vegetable crop surfaces are treated as the single surface, "agricultural fields."

TABLE 3.1. Land Uses Currently Implemented in DECON

Residential	Parking Lots
Commercial	Grain Crops
Industrial	Vegetable Crops
Street and Roads	Orchards
Wooded Areas	Vacant Land

The transformations that are difficult are those involving residential, commercial and industrial land uses. These comprise roofs, exterior walls, interior walls, floors, lawns, paved surfaces, windows and building contents. These last two surface categories are not currently implemented. Exterior walls, interior walls, floors and paved surfaces have been further subdivided to reflect differences in surface characteristics that significantly affect the method, cost or efficiency of decontamination.

In addition to the land uses presented in Table 3.1, automobiles are also treated. Four "surface" types are associated with these: exteriors, interiors, tires, and engine and drive train.

Major land use categories that are not currently implemented include public and quasi-public property, recreational areas, military installations and wet areas. Public and quasi-public property can be treated as commercial property, recreational areas can be handled by treating them as a combination of vacant land, lawns, and wooded areas, and military installations can be treated in a similar fashion. Wet areas present their own peculiar set of problems; consequently, such areas have been ignored in our analyses to date.

A final category that should be mentioned concerns building contents. Because of the tremendous variety of surfaces involved here, and because of the extreme variation in contents from one building to the next, no attempt has yet been made to treat this category.

3.2.3 Value of the Contaminated Property

A third type of site-specific information to be contained in the site database relates to property values. Property values are used in determining when to decontaminate a property. The more valuable a property, the more quickly it should be decontaminated, other things remaining the same.

Property value information is typically available from the local taxing authority. Another useful source is (Census of Governments, 1978). The information that is required need not be greatly detailed. A decision rule that is applied in DECON is to either decontaminate all of the property within a grid element or decontaminate none of it. This means that a single value is needed for the property in each grid element. Where a rectangular or radial grid is used, the site data model mentioned in Section 3.1.1 and described in detail in Appendix E can be used to allocate property values from political subdivisions to grid elements.

The property values should include all of the property that is evaluated for decontamination. This includes public property, for example, but excludes building contents. The value of public property is accounted for by multiplying the value of private property by the factor 1.95 (see Census of Governments, 1978).

3.3 SOFTWARE TOOLS FOR PREPARING THE SITE DATABASE

Several programs have been written to assist in the preparation of the site database. These include programs to accommodate rectangular, radial and irregular grids. Among these are programs and subroutines for:

- determining dose at any downwind location on or off the plume centerline
- generating the grid pattern for a radial grid, given the accident parameters and the distance intervals
- transforming land use areas into areas of surfaces, by surface categories
- using information based on political subdivisions for imputing information to grid elements
- using a stochastic process to assign property values when alternative information sources are inadequate.

These programs are all oriented toward providing site information in a form compatible with the requirements of DECON. This means providing for each grid element: 1) the pre-accident value and the post-decontamination value of property; 2) a measure of the degree of contamination on horizontal, exterior surfaces; 3) the distribution of property by type of surface; and 4) the area of the grid element. This information is contained in a random file, with one record per grid element to facilitate rapid processing. Additional information on these software programs is presented in Appendix E.

4.0 DECON - A COMPUTER PROGRAM FOR ESTIMATING DECONTAMINATION/ INTERDICTION COSTS AND SCHEDULES

In this section we describe a computer program that has been developed to utilize the information developed in Chapters 2 and 3 of this report. The computer program, called DECON, is designed to complement CRAC2, another computer program developed for the NRC to estimate the off-site health and economic consequences of severe radiological accidents at nuclear power plants.[2] DECON operates in interactive mode on an IBM Personal Computer and IBM compatibles. The current implementation requires 256K RAM, and a hard disk is recommended but not required.

To provide the reader with a basis for evaluating the extent to which DECON can complement the capabilities of CRAC2, we provide in the next section a brief description of CRAC2 as relates to decontamination and interdiction assessment.

4.1 METHODS USED IN CRAC2

The methods developed in this study and the computer program DECON, prepared in conjunction with this study, are designed to complement CRAC2. So that the differences between CRAC2 and DECON will become clear, we provide here a summary of the CRAC2 methods as they relate to the decontamination of nonagricultural land.

DECON and CRAC2 use the same accident grid. However, in the case of CRAC2, it is up to the user to provide a demographic data base that conforms with the boundaries of the grid. Even then, the only site-specific demographic information that CRAC2 can utilize is population data and habitable land fractions. In addition, the user supplies CRAC2 with: 1) the decontamination cost for residential, business and public areas (expressed in dollars per person); 2) the compensation rate per year for residential, business and public areas (expressed as fraction of the value); and 3) the value of residential, business and public areas (expressed in dollars per person). These values are applied to all of the grid elements within the accident grid. Obviously, CRAC2 has relatively little capacity to differentiate property values and land uses within the accident grid.

CRAC2 is set up so that each grid element receives one of the following classifications:

- no decontamination or interdiction required
- milk interdiction required
- crop interdiction required
- milk and crop interdiction required

[2] For a discussion of the capabilities and limitations of CRAC2, see Tawil et al. 1984.

- people must be relocated for less than 10 years
- land must be totally interdicted and people permanently relocated.

If a grid element is to be decontaminated, the cost of decontaminating nonagricultural property is assumed to depend only on the population within the grid element, the population density and the habitable land fraction. In particular, it is assumed not to directly depend on the types of surfaces to be decontaminated, on the concentrations of contaminants, or on the time lapse before decontamination is undertaken. Indeed, CRAC2 provides no information as to when decontamination actions would begin.

While CRAC2 assumes a constant cost per person to decontaminate residential, business and public areas, in practice such costs are likely to vary considerably from area to area. First, costs can vary substantially, depending upon the mix of residential, business and public property within a grid element. Second, even within similar property types, the cost of decontamination can vary considerably. Third, because decisions on whether or not to decontaminate should be based in part on the value of the property in question, using highly aggregate property values can produce misleading results. Finally, CRAC2 does not explicitly consider alternative methods for decontaminating property; either property is decontaminated at some pre-specified cost, or it is not decontaminated. In reality, there are a number of techniques that can be used to decontaminate property. These techniques vary significantly in both cost and effectiveness. A realistic decontamination scenario would require that cost-effective methods be applied.

CRAC2, while very useful in providing crude estimates of various accident costs, has a number of weaknesses. The current research is designed to reduce if not eliminate a number of these weaknesses while at the same time offering the user a similar degree of convenience. In the next section we develop a data base consisting of a number of decontamination methods that can be used on a variety of surfaces. DECON will use this data base to make optimizing decisions relating to decontamination activities.

While the likelihood of a reactor accident with significant off-site radiological contamination is remote, such accidents make a large contribution to total accident risk because of the enormity of the consequences. Site restoration costs and property losses account for a large share of off-site accident costs. For this reason, obtaining a reliable assessment of these is important in the evaluation of accident risk.

As already noted, CRAC2 provides estimates of major categories of health effects and estimates of evacuation costs, relocation costs (including lost wages and salary income), the cost of decontaminating property (based on the cost of decontaminating roofs, paved surfaces, lawns, and agricultural land) and the cost due to loss of use of property that must be interdicted. Results from CRAC2 suggest strongly that the land interdiction and decontamination costs tend to dominate the estimated off-site accident costs. Although these costs weigh so heavily in the CRAC2 consequence analysis, the estimates themselves are based on very rough approximations. It was therefore felt that a more rigorous approach to estimating these was appropriate, especially in view of the important role that consequence analysis plays in formulating safety-related policies.

4.2 INFORMATION PRODUCED BY DECON

In addition to producing cost information regarding decontamination and property losses, DECON also produces a wide variety of information that would be particularly useful for developing site restoration strategies. This information includes:

- the decontamination method used on each surface
- the rate at which the decontamination method is applied
- the type of labor used in the method
- the type of equipment used in the method
- the major materials required
- the efficiency of the method in reducing inhalation and external dose
- dose to radiation workers
- dose commitment from surface exposure.

The above information can be provided at different levels of detail. For fine analysis, breakdowns by surface type within each grid element can be produced. At more aggregate levels, there are summaries by grid element, groups of grid elements, and for the entire contaminated area.

4.2.1 Maximizing Property Values through Site-Restoration Actions

The basic principle upon which DECON operates is to minimize the social costs associated with site restoration. Although certain external effects and health effects are not considered, DECON does succeed in minimizing a major subset of the estimated accident costs.[3] Essentially, the program begins with the pre-accident value of the property within each grid element. It then makes several adjustments to the property's value depending upon what action is taken. We now consider four specific effects of the accident on property values.

4.2.1.1 Residual Contamination

One factor that directly affects the future value of the property relates to the cleanup criteria. The more thoroughly the contaminants are removed, the smaller will be the residual contamination. Regardless of how little residual contamination remains, however, it still seems likely that the public would perceive some health risk associated with the decontaminated property. Furthermore, the effect of these perceptions on property values would likely vary with function. Residential property values could be expected to be more adversely affected than industrial property, and agricultural land values more adversely affected than either of these. While there is no clear evidence on how much

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[3] For a detailed discussion on the social costs of a severe reactor accident, see Tawil et al. 1984, especially Chapter 7.

property values would decline under various cleanup criteria, DECON allows the analyst to select a set of adjustment factors--one factor for each land use category. These can be varied in conducting a sensitivity analysis.

DECON adjusts post-accident property values for residual contamination as follows. If $\underline{k}$ is the adjustment factor, V_b the pre-accident property value, and V_o the post-decontamination value of the property, then

$$V_o = kV_b$$

The magnitude of $\underline{k}$ should depend both on the type of property and the level of residual contamination.

4.2.1.2 Deterioration and Obsolescence

It was observed that ownership costs include the effects of obsolescence and deterioration, the latter of which could be quite substantial if the property is neglected for several years until it is decontaminated. As with residual decontamination, deterioration and obsolescence losses are likely to vary for different types of property. For example, because of the obsolescence factor, industrial properties are likely to depreciate more rapidly than residential properties; they may both deteriorate at the same rate. On the other hand, vacant land would neither deteriorate nor become obsolete.

To account for losses due to deterioration and obsolescence, DECON permits the analyst to select a set of factors--one for each land use--for these ownership costs. These factors express the annual percentage rate of property loss due to deterioration and obsolescence. The formula below makes explicit the value of a property V_p, with originial value V_o, after T years of deterioration and obsolescence.

$$V_p = V_o(1-df)^T$$

In this formula $\underline{df}$ is the annual depreciation factor due to deterioration and obsolescence.

4.2.1.3 Loss of Use of Property

While property is contaminated, it is unlikely to be used. The loss in the flow of services from it constitutes a third factor affecting its value. It is apparent that the longer the property remains in disuse, the lower will be its current value, which is equal to the net present value of the expected flow of its services over its lifetime, less any scrap value. Hence, the current value of a property that will remain in disuse over the next $\underline{T}$ years is given by

$$V_f = V_p/(1+r)^T \qquad (V_f \text{ greater than S, the current scrap value})$$

where $\underline{r}$ is the discount rate and the other variables are as previously defined. The discount rate in DECON is user-selectable, with a default value of 10 percent.

4.2.1.4 Decontamination Costs

Finally, the cost of decontaminating a property will directly affect its pre-decontamination value. The more costly the required decontamination, the less valuable the property will be. If the decontamination costs, C, are incurred in year T, the current value of the property is simply

$$V_c = V_f - C/(1+r)^T$$

If we now put these four relationships together to determine the current value of a property, V*, following the effects after T years of residual contamination, deterioration and obsolescence, loss of use and the costs of decontamination, we have

$$V^* = \frac{kV_b(1-df)^T - C}{(1+r)^T}$$

Each of the four factors affecting V* is separately identifiable in the above relationship, and each can be altered in the program to determine the sensitivity of the results to any or all of them.

It should be noted that expected future changes in asset values--i.e., changes as expected by the market place--should not be embodied in the depreciation factor, since these expected changes are already embodied in the pre-accident value of the asset. For example, consider a forest in which the trees are undamaged by the radiological contamination and their normal growth occurs unimpeded throughout the period that the property remains contaminated. Because the forest is expected to appreciate in value, this expectation is embodied within the current value of the forest. This appreciation should not be considered when selecting the appropriate depreciation factor, which probably should be close to zero in this particular case. (Taxes are also a part of ownership costs, but they are not included here since we are evaluating social rather than private costs.)

4.2.2 Algorithm to Maximize Property Values

The algorithm upon which DECON is based works to maximize V* by varying decontamination costs, C, and time of decontamination, t. The way in which this is done can be viewed as a progression of steps, which are illustrated in the flow diagram depicted in Figure 4.1. The process assumes that all decontamination activities take place and all costs are incurred on an anniversary date of the radiological release. Violation of this assumption will not significantly affect the results.

If an area needs to be decontaminated, it will not be decontaminated before the first anniversary date. Therefore, the radionuclides are allowed to decay and weather for a year before analysis begins. The CRAC2 weathering and decay models are used to develop a set of weathering and decay factors, which are then stored in DECON. One factor is required for each of the 30 time periods used in the analysis. (The number of time periods is also user-selectable.)

Then begins the processing of the property to be decontaminated. The first grid element is selected, and each of the surfaces within that grid

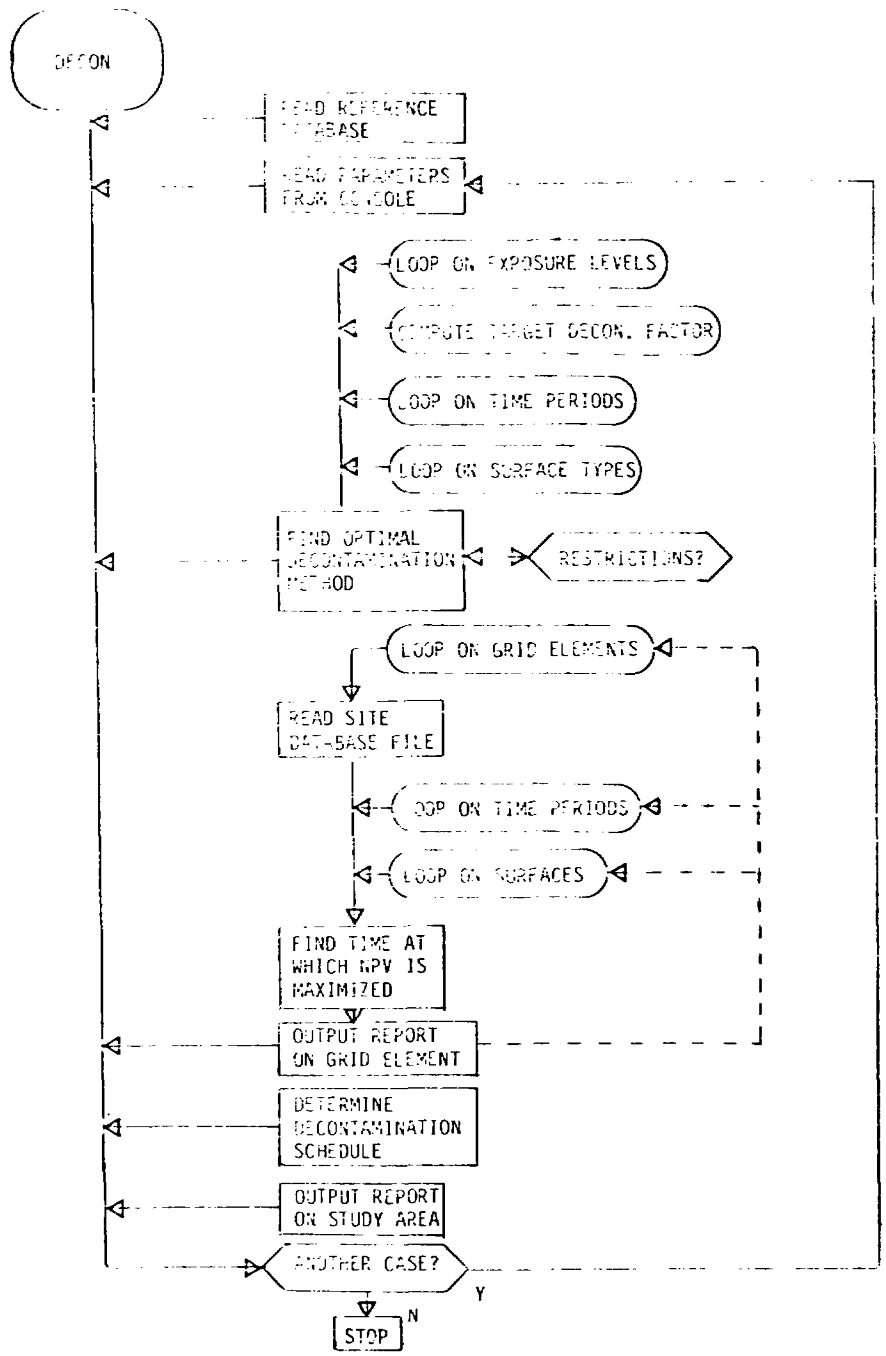

FIGURE 4.1. Primary Logic of DECON

element is sequentially processed. For the first surface, a target decontamination factor is calculated.[4] The decontamination methods within the reference database are then searched to identify all relevant methods that have a decontamination factor greater than or equal to the target decontamination factor. The method with the lowest cost among these is selected. The rest of the surfaces within the first grid element are processed in the same manner. V* is then computed for this grid element at time t = 1 year after release. DECON then proceeds to process each of the remaining grid elements.

The contaminants are then weathered and decayed for another year, and the process is repeated for year two. The processing continues until V* has been determined for each grid element and for each of the 30 years. The process ends by identifying for each grid element the year in which V* is maximized.[5]

4.2.3 Effects on Property Values When No Decontamination is Required

It may turn out that some surfaces within a grid element or even the entire grid element may require no decontamination; this happens whenever the target decontamination factor is less than or equal to 1.0. If some of the surfaces within the grid element require decontamination, then all of the property within the grid element is assumed to suffer losses due to depreciation, loss of use, and residual contamination. If none of the surfaces within the grid element require decontamination, it is assumed that none of the property loses value.

4.2.4 Property that Cannot Be Decontaminated

A different situation which may arise is that some surfaces within a grid element are so severely contaminated that none of the methods in the reference database are sufficiently powerful to successfully decontaminate them. In other words, the decontamination factor for the most powerful method available is still less than the target decontamination factor for that surface. The decision rule that DECON applies here is that if one or more surfaces within a grid element cannot be decontaminated at a given time, none of the surfaces within the grid element are decontaminated at that time. In extreme cases, the property cannot be decontaminated within the 30-year period encompassed by the analysis.

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[4] A decontamination factor is defined as the ratio of removed contamination to residual contamination, where contamination can be measured in terms of dose rate, dose commitment, or other comparable measure, depending upon the analyst's interests. The target decontamination factor is simply the ratio of the measured contamination on the surface to the cleanup criterion.

[5] This discussion describes the logic underlying DECON. DECON itself actually follows a somewhat different flow diagram, which allows it to process the results in a small fraction of the time that would otherwise be required.

4.2.5 Properties with Negative Net Present Values

In applying the above algorithm to maximize property values, it may turn out in a heavily contaminated area that the best result when the property is decontaminated gives a negative value for V*. In other words, if the evaluation is made exclusively on the factors explicitly considered, it is not cost-effective to decontaminate the property; rather it should be interdicted. However, there are some other considerations that should be taken into account prior to making such a decision. If a property is not decontaminated, it presents a potential hazard to nearby property through resuspension of the contaminated particulates. In such situations, one needs to evaluate the potential hazard and to compare this with the cost of mitigating the hazard, say, by applying and maintaining a fixative.

When the best decontamination solution for a grid element still yields a negative value for V*, a net present value of $0 is reported for the property. Negative values are not reported. However, in the report summarizing all of the grid elements evaluated, the potential savings from interdicting rather than decontaminating such property is presented. Since a government or utility buy-out could be involved, potential savings are measured both in terms of the pre-accident and post-decontamination property values. However, only the latter value is relevant to evaluating the net benefit to society from not decontaminating.

4.2.6 Contamination Model

It is unreasonable to expect that all surfaces will receive the same amount of contamination. In particular, vertical walls and interior surfaces will become less contaminated than horizontal, exterior surfaces in the same vicinity. DECON currently uses the following default values with regard to surface contamination.

- Exterior vertical walls receive 10 percent,
- interior floors receive 50 percent,
- interior vertical walls receive 5 percent, and
- automobile interiors receive 30 percent

of the contaminated mass loadings on horizontal, exterior surfaces. These numbers assume sufficient warning has been given to the public so that structures and autos are properly closed up prior to evacuation. This includes turning off ventilation systems and closing doors and windows. The above figures for interior floors and automobile interiors are based on (Alonza et al., 1979); the other two figures are based on the authors' judgment.

As already noted in the discussion on efficiencies (see Section 2.2.1), contamination levels are based on the mass loadings of radioactive contaminants at the time of the plume passage. Subsequent transmigration of contaminants is ignored. The earlier discussion suggested that at least some of the effects of transmigration would be mitigated by effective decontamination strategies.

4.3. SPECIAL FEATURES

DECON has been designed with many special features to facilitiate its use in site restoration analysis. To assist the user, DECON is almost entirely menu driven. Several different output formats are available through the report writer. Detailed information by surface can be produced for individual grid elements, or summary data only can be selected. Summaries are for the entire study area and, optionally, for grid elements. Other special features are described below.

4.3.1 Subarea Analysis

One of the features of DECON is its ability to perform a subarea analysis on an irregular area. For example, if an irregular grid is used to characterize the accident area, where each grid element is a township, then one may have occasion to analyze a subgroup of contiguous townships, say those within a county. Pairs of grid element numbers are entered to define the subarea. Grid elements whose numbers fall within the interval defined by the pair of numbers are included in the subarea. Thus, if the pair (72,79) is entered, grid elements 72,73,...,79 become included. Up to 100 pairs of numbers can be used to define the subarea. This technique has proven especially useful when applied to a rectangular grid (see Tawil, 1983). This application involved a decontamination analysis of an area of 3.8 million square feet, and divided into grid elements of size 50' by 50'. Several irregularly shaped subareas were analyzed.

4.3.2 Pre-Rain Analysis

If precipitation falls on surfaces after they have been contaminated, in many cases the decontamination process becomes more difficult and more costly. (On pervious surfaces, such as land, precipitation carries the contaminants below the surface level, causing a reduction in external exposure.) Efficiencies have been estimated for all of the methods assuming both rain prior to decontamination and no rain. This enables a comparison to be made to ascertain the potential savings from decontaminating surfaces before they become wet. While in most circumstances it would be extremely unlikely that decontamination could be completed before precipitation falls on the surfaces, some preventive measures might prove worthwhile. For example, if plastic sheeting is used to cover roofs until they can be decontaminated, in some situations this measure could obviate the need to replace the entire roof. Protective coverings might prove cost-effective on other surfaces as well.

Another option involves vacuuming selected exterior surfaces prior to precipitation. Vacuuming is one of the least expensive methods for decontaminating a number of surfaces, and it has a reasonably good removal efficiecy. Furthermore, over many surfaces, it can be applied at a very fast rate. This combination of characteristics suggests that vacuuming techniques could prove effective at removing loose radioactive particles from contaminated surfaces, provided that the required manpower and equipment can be mobilized before the surfaces become wet. Streets, highways, roads and parking lots are particularly good candidates for this decontamination strategy. Roofs might also be a candidate, allthough the effective rate for vacuuming roofs is just 81 square meters per hour, as compared with 8,600 for streets. DECON is able to evaluate the potential cost savings from early vacuuming of these and other surfaces.

4.3.3 Restrictions

In certain circumstances, it may be desirable to restrict the use of particular operations or methods on certain surfaces. For example, methods that utilize water on agricultural lands could create problems associated with root uptake and biological concentration of radionuclides; the transport of radionuclides through the soil could also threaten shallow, underground water supplies. In developed areas, water methods may contaminate sewage systems and water treatment facilities. In situations such as these, DECON can be applied with a restriction placed on one or more of the methods using water and on one or more of the surface types. When DECON is operating under this mode, each candidate method is searched for the restricted operation. If the method is found to contain this operation, it is excluded from use on the specified surfaces.

There are a variety of other reasons why one may wish to restrict the use of specific operations. They include

- equipment requirements cannot be met
- materials requirements cannot be met
- labor requirements cannot be met
- insufficient working area for using large equipment
- terrain unsuitable for selected method
- roof too steep.

Up to 100 restrictions can be imposed in any one case. If the restrictions apply to more than one, but not all, of the surfaces, each surface will use up one restriction. For example, if four operations are restricted on 10 surfaces, 40 restrictions are used up.

4.3.4 Required Methods

In addition to restricting the use of certain operations or methods, one can also cause DECON to impose a specified method on one or more specifed surfaces. One specific case in which this option applies relates to vacant land. It may be necessary to clear vacant land before it is scraped, depending upon what is on the surface. The specified efficiency is the same with or without clearing, but the cost with clearing will be greater. Thus, the option without clearing will always be selected by DECON. If the initial run of DECON indicates scraping vacant land as the preferred option, and the land is known to be heavily overgrown with weeds or brush, then in a second run one can simply require DECON to use scraping with clearing.

Another useful application of this technique is to determine the incremental cost of using an alternative method. For example, even though the cleanup standard is met by the selected method, it may be possible to use a much more effective method with only a small cost increase. Alternatively, it might be possible to use a far less expensive method, but one that barely fails to meet the cleanup standard. (The reader is reminded that the reported efficiencies of the methods may not be very accurate; in many instances they have had to be estimated using only indirect evidence.)

The limitation of 100 restrictions per case noted in Section 4.2.3 must also include the number of required methods imposed for any single case. Thus, the 100 figure is the maximum number of restricted plus required methods. Two further observations are noted. First, while restrictions can be imposed only on operations, the current option applies to methods (methods include operations, but the reverse is not true). Secondly, DECON does not check for inconsistencies; i.e., it does not check whether different methods have been specified for the same surface. In such cases, the last requirement entered will be the one that is operative.

4.3.5 Variation in Exposure Levels

Another application of DECON is to allow cleanup standards to be varied according to the type of surface. The potential usefulness of this feature is based on the observation that human exposures to different surfaces vary considerably. Housing interiors, for example, would usually present high exposures, while highways and wooded areas would tend to offer low exposures. The exposure factors are defined as being inversely proportional to the target decontamination factors, with a base value of 1.0. Thus, an exposure factor of 2.0 means that it would be necessary to remove from a surface 50 percent of the contaminants that would have been required with an exposure factor of 1.0.

Practical applications for this strategy include, for example, allowing vacant land and wooded areas to have higher levels of residual contamination and at the same time requiring residential interiors to achieve lower levels of residual contamination. If this option was exercised in practice, it would be important to ensure that no individual received high doses from surfaces rated for low exposures. For example, work places could tolerate higher residual levels provided that a maximum number of hours per unit time on the premises could be enforced.

4.3.6 User-Selectable Parameter Values

The user can redefine the values of several of the parameters used in DECON. These parameters include the

- depreciation factor for each surface
- adjustment factor for property value based on residual contamination
- discount rate
- distance for hauling radioactive wastes
- shielding factors for protective gear worn by radiation workers
- wealth loss from removal of trees in forest
- wealth loss from removal of trees in orchard
- radiation limit
- exposure factors
- number of time periods to be analyzed.

In addition, the user may also specify factors by which to increase or decrease labor, capital and/or materials costs. This feature can be used to adjust costs for inflation. It can also be used to 1) increase the cost for labor because the work is done in a radioactive environment; 2) increase the effective costs of labor and capital because working in protective gear reduces worker productivity; and 3) increase the costs of labor and capital because operations are being performed on a small scale.

4.3.7 Future Capabilities

Several potentially attractive features could not be included in the present version of DECON due to resource constraints. These features are described briefly below. DECON has been designed to allow most of the following to be added with a very modest level of effort.

Population Dose. A useful concept in planning a site restoration strategy is the population dose averted by alternative mitigating actions. Such actions would include population relocation and selection of the cleanup standards.

Surveying and Monitoring Costs. Surveying and monitoring costs following severe radiological accidents have been developed by PNL in research being conducted for the Office of Radiation Programs, U.S. Environmental Protection Agency. These costs have been structured so that they can be added to DECON with a minimum of coding.

Weathering. DECON currently uses external dose information from CRAC2 that assumes weathering. Nearly all of the weathering effect is the result of precipitation transporting the contaminants downward into the soil. Because the weathering effect can be expected to vary significantly with the amount of rainfall, using site-specific rainfall information should result in improved estimates in the decontamination analysis. Rainfall could be treated simply as the application of a water method, but without the associated costs.

Disposal Operations and Costs. Disposal activities are not considered in the current version of DECON. This addition, together with the surveying and monitoring costs, would encompass the major activities involved in site restoration. The disposal alternatives need to be researched, with costs and input information developed. The results can be easily incorporated within the existing framework of DECON.

Effects on Productivity of Protective Gear and Temperature. Working in protective gear will diminish the rate at which decontamination activities can proceed. Working under high temperature conditions will reduce the output rate even further. To incorporate these adjustments into DECON would require: 1) establishing the environmental conditions that would necessitate the wearing of protective gear; 2) identifying the type of protective gear that should be worn in various situations; 3) determining the effect of wearing the protective gear on worker productivity; and 4) establishing the relationship between ambient temperature and the work cycle.

Number of Autos. DECON currently produces information on the decontamination of automobiles, including exteriors, interiors, tires, and drive train. The results, however, are reported for only one "unit" of automobiles, where the number of automobiles per unit is equal to the scale factor used in presenting the results. Because automobiles would almost certainly be the principal means for evacuating an area, it is not clear how many would remain within the contamination zone. Research on evacuations from natural disasters, such as hurricanes, could provide some useful information.

4.4 FLEXIBILITY OF DECON

DECON has been structured to provide great flexibility with regard to new features, such as those just described, and revisions. Changes in the cost of decontamination methods and revisions of the efficiencies of these methods can be readily incorporated into the database. We have already noted the ability to change labor, capital and/or material costs across the board through the use of user-selectable factors. Also, as noted in earlier sections, the efficiencies of many of the decontamination methods employed in DECON have not been validated through field experiments. Should such experiments be performed, incorporating the results into DECON would be a trivial exercise.

The software has already been included for handling 22 types of surfaces, with 183 operations defined and 347 methods. The capability to expand this further has been built into the code. There is also large flexibility in the number of time periods, dose-commitment periods, affected organs, and the number of spatial intervals.

5.0 A CASE STUDY USING DECON

In this chapter we demonstrate the capabilities of the reference data base and of DECON by conducting a site restoration analysis for a severe reactor accident at a hypothetical reactor site. The reactor accident simulation was performed with the CRAC2 model. A radial grid is used to characterize the accident site. The relevant parameters that describe the accident are presented in the following section, and the results are discussed in Section 5.2.

5.1 PREPARATION FOR CONDUCTING THE CASE STUDY

To retain the maximum degree of flexibility, the computer programs used in the analysis have been maintained as separate modules. They are: CRAC2, the dose model, the grid model, the site data model, and DECON. CRAC2 and the dose model run on a VAX minicomputer, while the others run on an IBM Personal Computer. The grid model and site data model, while performing separate functions, are combined into a single computer program. We now describe the functions of these programs.

5.1.1 Purpose of the Models

First, CRAC2 is run to produce a file of ground concentrations. Then, the dose model is used to generate doses or dose commitments at pre-specified distances on the plume centerline. The dose model uses the CRAC2 ground concentrations as input. The grid model is run next. This model organizes the radial grid pattern, determines the number of sectors that require decontamination and identifies the grid elements within those sectors that must be decontaminated. The grid model also computes the dose or dose commitment at the midpoint of each grid element. The outputs of the dose model are used in this computation.

The fourth program, the site data model, performs two primary functions: first, it takes information based on political subdivisions and imputes corresponding information to the individual grid elements. This information includes property values and areas by land use category. Secondly, it takes the imputed land use data and transforms it into areas by surface type. The site data model then creates a random access data file with one record for each grid element to facilitate rapid processing. Each record contains the complete site information required by DECON. Finally, DECON performs the site restoration analysis, using information from the reference database and the site database. The grid model and site data model are described in greater detail in Appendix E.

5.1.2 Running the Models

The first step was to run CRAC2 to generate the test ground concentration file. The sample problem was taken from the CRAC2 reference problem set supplied by Sandia National Laboratory with the CRAC2 program. Data used in the sample problem to generate the downwind ground concentrations were as follows:

- The weather sequence is based on a Pasquill D weather stability. A wind speed of 4 miles per hour is assumed. Other relevant release category parameters are: time of release - 3 hours; release duration - 2 hours; release height - 10 meters; and release energy - 0.

- The radionuclide release term is based on an SST2 accident. An SST2 is a severe core melt accident with significant releases of radionuclides. The inventory release fractions are: Xe, Kr Group - 9 x 10^{-1}; I Group - 3 x 10^{-3}; Cs, Rb Group - 9 x 10^{-3}; Te, Sb Group - 3 x 10^{-2}; Ba, Sr Group - 1 x 10^{-3}; Ru Group - 2 x 10^{-3}; La Group - 3 x 10^{-4}.

- Sixteen downwind distance intervals were specified. Measured from the release point, they are: 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 85 and 100 miles.

In the next step the dose model was run to produce a series of 70-year dose commitments and a set of weathering and decay factors. These latter are used by DECON in determining the optimal decontamination schedule.

The grid model was then run to organize the radial accident grid. A user input to this program is the cleanup criterion, since this will affect the size of the geographic area that must be analyzed. The cleanup criterion selected for this case study is a 70-year dose commitment of 10 rem. The grid pattern and numbering scheme generated by the grid model is produced in Figure 5.1. Although we had originally specified 16 distance intervals, the grid model indicates that just 10 of these will suffice to include the area requiring analysis.

The grid model was also used to compute 70-year dose commitments measured at the midpoint of each of the numbered grid elements. The results are reported in Table 5.1. Given our selected cleanup criterion of 10 rem, it is clear that some of the off-center grid elements will not be relevant to the analysis. In particular, grid elements 4 through 10 and 24 through 30 will require no treatment.

TABLE 5.1. 70-Year Dose Commitment by Grid Element (Rem)

Grid Element	70-Yr. Dose Comm.	Grid Element	70-Yr. Dose Comm.	Grid Element	70-Yr. Dose Comm.
1	595.6	11	4113.	21	595.6
2	46.16	12	984.6	22	46.16
3	18.07	13	474.4	23	18.07
4	9.477	14	288.9	24	9.477
5	5.732	15	198.2	25	5.732
6	.9169	16	89.59	26	.9169
7	.1362	17	40.30	27	.1362
8	.09769	18	23.54	28	.09769
9	.06629	19	15.65	29	.06629
10	.04589	20	11.25	30	.04589

The last step before running DECON is to run the site data model. For this case study, data are used for a set of fictitious counties. One main function of the site data model is to take these county data and use them to produce corresponding information for the grid elements of interest. However, to implement this capability, it is first necessary to determine how each grid element is partitioned among the counties. In practice, this can be done by superimposing the CRAC2 accident grid on a map of the accident site that shows the county boundaries. An estimate is then made of the proportion of each grid element occupied by each county. An example of this is presented in Table 5.2, which shows how the fictitious counties are divided among the grid elements. For example, grid element 20, which is 25 to 30 miles from the accident site in the direction of the plume,is apportioned as follows: 20 percent is in Albemarle County, 75 percent is in Easton County, and only 5 percent is in Fargo County.

TABLE 5.2. Percentage Distribution of Each Grid Element, by County

Grid Element	County
1	Albemarle (100%)
11	" "
21	" "
2	" "
12	" "
22	Albemarle, Beauford (50/50)
3	Albemarle (100)
13	" "
23	Albemarle, Beauford (40/60)
14	Albemarle (100)
15	" "
16	" "
17	" "
18	" "
19	Albemarle, Easton (50/50)
20	Albemarle, Easton, Fargo (20/75/5)

The next step is to develop land use information for each county. Specifically, information on the area of each land use category within each county is required. Land use categories that are typical of those available from state and local agencies are presented in Table 5.3. The assumed distribution of acreage for this case study is presented in Table 5.4.

In addition to the land use information, the following information is required for each county:

- total acreage,
- total population
- total property value.

TABLE 5.3. Representative Land Use Categories

Single-Family residential	Wooded areas
Multi-family residential	Agricultural land
Industrial	Commercial/Public
Streets and Roads	Vacant Land

TABLE 5.4. Distribution of Land According to Land Use Within Accident Area, by County

	Cooper	Beauford	DePlains	Albemarle	Easton	Fargo
Single Family	.106	.087	.242	.196	.073	.169
Multi Family	.017	.004	.044	.015	.223	.017
Industrial	.017	.004	.044	.015	.223	.020
Commercial/Public	.036	.022	.063	.036	.155	.045
Streets/Parking	.030	.027	.074	.050	.173	.069
Vacant Land	.189	.083	.111	.086	.108	.102
Recreational	.015	.015	.038	.049	.088	.028
Agricultural	.297	.511	.151	.375	.015	.155
Forestry	.273	.233	.206	.158	.027	.291
Water	.020	.012	.048	.016	.065	.103

The assumed data are presented in Table 5.5. Typically, property value data relates to taxable property; such data would therefore exclude the value of public property. To obtain the value of all property, we multiplied the value of taxable property by 1.95, the factor given in (Census of Governments, 1978).

TABLE 5.5. Data for Counties in the Accident Area

	Population	Taxable Property Value	Total Acreage
Albemarle	343,621	11,421	317,446
Beauford	316,660	5,153	487,679
Cooper	479,211	7,545	399,995
DePlains	555,007	8,589	122,238
Easton	1,688,210	15,191	91,970
Fargo	471,650	5,061	143,998

The last information that is required to run the site data model is the population count for each of the affected grid elements, as shown in Table 5.6. We note that population counts comparable to these have been collected by Oak Ridge National Laboratory for the NRC for all existing reactor sites.

TABLE 5.6. Distribution of Households Within Accident Area

Grid Element	Households	Grid Element	Households
1	9	4	225
11	21	14	104
21	0	24	2,105
2	35	15	116
12	52	16	2,826
22	164	17	17,838
3	121	18	24,078
13	86	19	70,622
23	104	20	195,341

The data described above should be readily available for most reactor sites. The information likely to be the most difficult to obtain is the land use information. However, even this should be widely available for most developed areas around reactors.

To process this information, the site data model first transforms the county-based data to coincide geographically with the elements of the CRAC2 accident grid; it then transforms the land use areas into areas by surface types. As already noted the current version of DECON handles the 22 surface types listed in Table 1.2. The relationships that are used to transform land uses into surface types are presented in Appendix E, Tables E.3.3, E.3.4 and E.3.5.

The information written to file by DECON for each grid element includes:

- the pre-accident value of the property
- the post-decontamination value of the property (set equal to 0.9 x the pre-accident value for this case study)
- the 70-year dose commitment
- the population
- the distribution of total surface area by type of surface
- the area.

This file is read directly by DECON.

5.2 RESULTS

The results of the site restoration analysis are presented in this section. DECON is used to explore various strategies aimed at minimizing the consequences of this simulated accident. First, DECON was run for the entire contaminated area. This run represents the base case and is reported in Section 5.2.1. A variety of different assumptions was then made and the results compared with those from the base case. In Section 5.2.2, some results are presented that show how the decontamination schedule is developed. In Section 5.2.3, a detailed printout for a single grid element is examined, and the information provided by this printout is explained. In Section 5.2.4 an analysis is conducted to illustrate the restricting of methods using water, and Section 5.2.5 demonstrates an application in which water is pre-specified as the method to be used on agricultural fields. Section 5.2.6 demonstrates how the exposure factors can be varied both to reduce expected dose and to reduce decontamination costs and property losses. In Section 5.2.7 DECON is used to produce information showing the tradeoff between cleanup standards and decontamination costs. Conclusions are given in Section 5.2.8.

5.2.1 Base Case

The base case analysis extends for a period of 30 years and assumes that 1) precipitation will fall on exterior surfaces prior to decontamination, and 2) site restoration measures must be applied to produce a 70-year dose commitment not to exceed 10 rem. Results for the base case are presented in Table 5.7, and encompass grid elements 1 through 30.

These summary results are given for 14 "exposure areas." An exposure area consists of all of the grid elements that have been contaminated to the same level. The various exposure areas were displayed in Figure 5.1. Note that grid elements 1 and 21, 2 and 22, and 3 and 23 are in the same exposure area because they have the same ground concentrations. If only summary results are wanted, the analysis is performed in terms of exposure areas rather than grid elements, as this greatly increases processing speed, especially when the number of grid elements is much larger than the number of exposure areas.

Near the top of Table 5.7 is the scale factor to be applied to all of the listed results that are expressed in dollars, square meters and man- and equipment-hours. The scale factor used throughout this case study is 1,000.

The first major result of the analysis is that total decontamination costs are $325.0 million. A total surface area of 509.8 million m^2 required decontamination, resulting in average decontaminations costs of $.64 per m^2. At the cleanup standard of 10 rem, 2.08 billion m^2 required no decontamination treatment. This area includes all of grid elements 4 through 10 and 24 through 30 (see Figure 5.1). Finally, nearly 700,000 m^2 of surface area were not decontaminated because of contamination levels that were too high to be treated with methods available in the reference database.

The property in the study area had a pre-accident value of $40.8 billion, and a present value worth immediately after the accident of $35.6 billion, for a net loss of $5.2 billion. Nearly eighty percent of this loss is due to a discount in the value of the property as a result of residual contamination, and most of the remainder is due to depreciation and loss of use of the property. Only $325 million is the result of decontamination costs. The discount factor, depreciation rate and discount rate are all assumed at 10 percent.

5.2.2 Decontamination Schedules

Summary results for each grid element indicate the year in which decontamination operations should be undertaken to minimize total property losses. Table 5.8 presents the summary results for grid elements 12 through 16. These

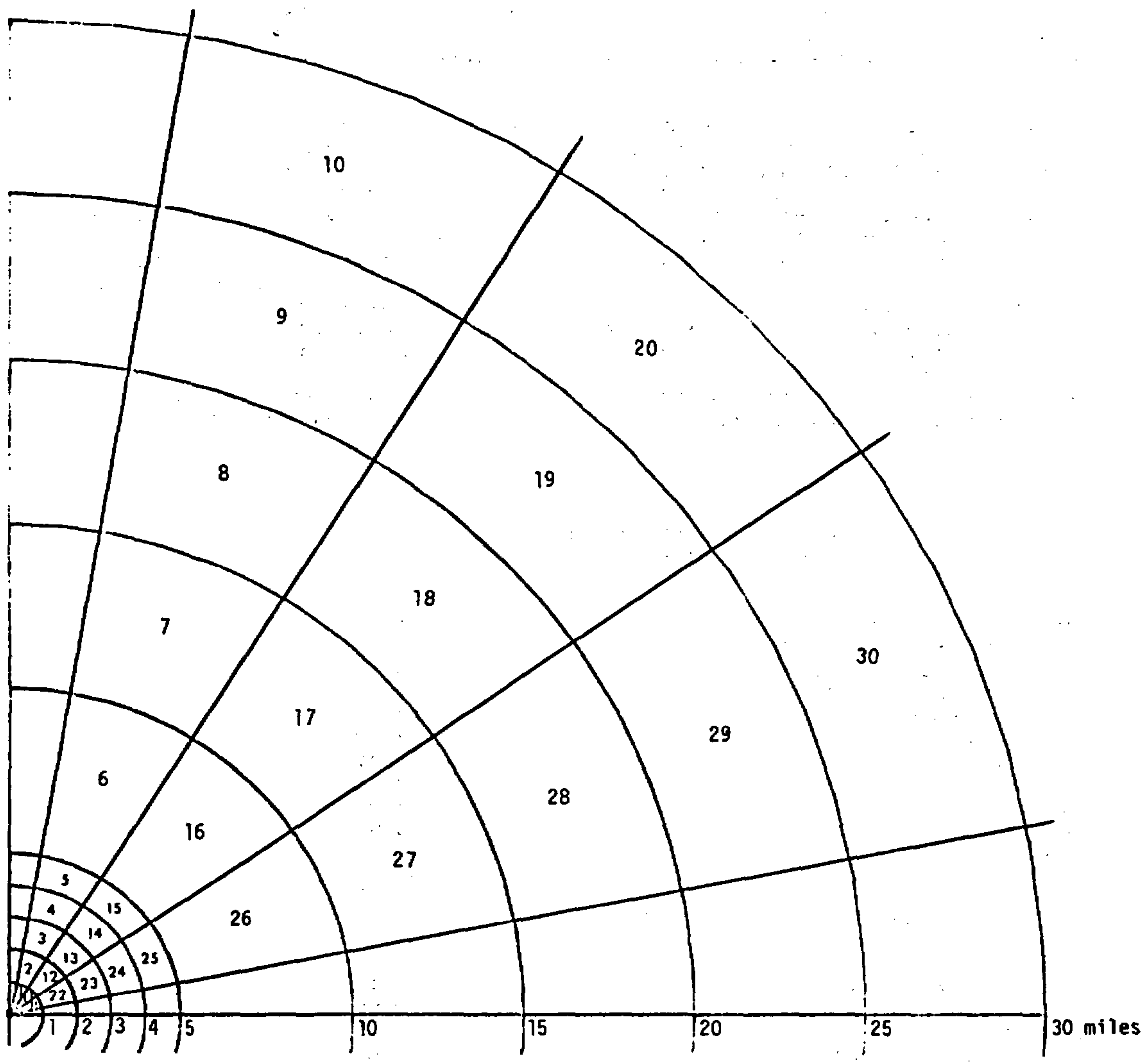

FIGURE 5.1 Radial Grid for Case Study

TABLE 5.7 Decontamination Results for the Base Case

SUMMARY RESULTS FOR EXPOSURE AREA 1 TO EXPOSURE AREA 14

```
*************************************************************
* MULTIPLY $'s, AREAS AND MAN/EQUIP-HOURS BY:     1.000E+03*
*************************************************************

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING      1.0000.
RADIATION LIMIT FOR ORGAN 1 IS ...............        10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........           30
TOTAL DECONTAMINATION COSTS ARE............. $      324954.
TOTAL AREA DECONTAMINATED IS.................     509798.0 SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $         .64
AREA REQUIRING NO DECONTAMINATION IS.........    2080324.0 SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....           .0 SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS .............. $   40798520.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $   36718670.
NET PRESENT VALUE OF PROPERTY IS ............ $   35640230.
TOTAL REDUCTION IN PROPERTY VALUE IS ........ $    5158288.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS ......     3445.892 MAN-REM.
SIZE OF RESIDENT POPULATION .................     2523837. PERSONS.
```

TOTAL FACTOR INPUT REQUIREMENTS
(MAN/EQUIPMENT HOURS)

DRIVER, HEAVY TRUCK	436.26
OPERATOR, MED. EQUIPMENT	1929.26
OPERATOR, LIGHT EQUIPMENT	4.13
OPERATOR, FARM EQUIPMENT	19.06
BUILDING LABORER	410.77
COMMON LABORER	267.23
CLEANING WORKER	911.79
FOREMAN	159.41
PILOT	5.91
FLIGHT CREWMAN	5.91
AIR GROUND CREWMAN	11.82
SPRAY OPERATOR	57.21
FRONT END LOADER	271.03
5000 GAL. SPRAY TRUCK W/PUMP&BOOM	4.15
BULLDOZER	37.49
AIRPLANE	5.91
ORCHARD BLAST SPRAYER	.17
TRACTOR W/PLOW	18.89
CHIPPING MACHINE	73.29
HYDRAULIC EXCAVATOR	70.43
VACUUM, HAND	902.22
PAINT SPRAY EQUIPMENT	57.21
VACUUMIZED STREET SWEEPER	.27
MOBILE STREET FLUSHER	2.09
SANDBLAST EQUIPMENT	.13
TOW TRUCK	15.00
GRADER	86.12
VEHICLE WASHING EQUIPMENT	7.23
DUMP TRUCK	417.11
SMALL TANK-SPRAY TRUCK	.27
ENGINE STEAM CLEANER	4.00

TABLE 5.7 (cont.)

TOTAL AREA DECONTAMINATED, BY SURFACE AND METHOD

SURFACE TYPE	METHOD	AREA (SQ. METERS)
AGRICULTURAL FIELDS	X	25655.
AGRICULTURAL FIELDS	A	18230.
AGRICULTURAL FIELDS	AG	20579.
VACANT LAND	W	8090.
VACANT LAND	A	25343.
WOODED LAND	TNX	10820.
WOODED LAND	TNx	8669.
WOODED LAND	TDh	965.
WOODED LAND	TX	9093.
LINOLEUM FLOORS	V	12608.
WOOD FLOORS	V	9582.
CARPETED FLOORS	V	20178.
CARPETED FLOORS	v	117.
CARPETED FLOORS	VF	117.
CARPETED FLOORS	vF	1929.
CARPETED FLOORS	vFF	120.
CONCRETE FLOORS	V	8748.
CONCRETE FLOORS	v	1885.
ASPHALT STRTS/PRKNG	W	14686.
ASPHALT STRTS/PRKNG	F	2037.
CNCRETE STRTS/PRKNG	W	12608.
CNCRETE STRTS/PRKNG	F	1768.
ROOFS	V	55001.
ROOFS	W	28529.
ROOFS	WW	3530.
ROOFS	VW	242.
LAWNS	W	117870.
LAWNS	WW	71250.
LAWNS	WWWW	207.
LAWNS	R	5455.
OTHR PAVED ASPHALT	W	2695.
OTHR PAVED ASPHALT	F	78.
OTHR PAVED CNCRETE	W	10795.
OTHR PAVED CNCRETE	F	319.

TABLE 5.8 Decontamination Schedule for Grid Elements 12 Through 16

```
SUMMARY RESULTS FOR GRID ELEMENT   12


****************************************************************
* MULTIPLY $'s, AREAS AND MAN/EQUIP-HOURS BY:      1.000E+03*
****************************************************************

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING       1.0000.
RADIATION LIMIT FOR ORGAN 1 IS ...............         10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........            30
OPTIMAL TIME TO DECONTAMINATE IS IN YEAR......            13
ANNUAL DEPRECIATION FACTOR IS.................           .10
DISCOUNT FACTOR IS............................           .10
DISCOUNT FOR RESIDUAL CONTAMINATION IS........           .10
TOTAL DECONTAMINATION COSTS ARE.............. $        4377.
TOTAL AREA DECONTAMINATED IS.................         1674.0 SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $         2.61
AREA REQUIRING NO DECONTAMINATION IS.........          353.4 SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....             .0 SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS .............. $       26449.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $       23804.
NET PRESENT VALUE OF PROPERTY IS ............ $         485.
TOTAL REDUCTION IN PROPERTY VALUE IS ........ $       25964.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS ......        24.715 MAN-REM.
SIZE OF RESIDENT POPULATION ..................          166. PERSONS.


SUMMARY RESULTS FOR GRID ELEMENT   13


****************************************************************
* MULTIPLY $'s, AREAS AND MAN/EQUIP-HOURS BY:      1.000E+03*
****************************************************************

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING       1.0000.
RADIATION LIMIT FOR ORGAN 1 IS ...............         10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........            30
OPTIMAL TIME TO DECONTAMINATE IS IN YEAR......             6
ANNUAL DEPRECIATION FACTOR IS.................           .10
DISCOUNT FACTOR IS............................           .10
DISCOUNT FOR RESIDUAL CONTAMINATION IS........           .10
TOTAL DECONTAMINATION COSTS ARE.............. $        7067
TOTAL AREA DECONTAMINATED IS.................         2791.0 SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $         2.53
AREA REQUIRING NO DECONTAMINATION IS.........          587.2 SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....             .0 SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS .............. $       44058.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $       39653.
NET PRESENT VALUE OF PROPERTY IS ............ $        7906.
TOTAL REDUCTION IN PROPERTY VALUE IS ........ $       36152.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS ......        37.029 MAN-REM.
SIZE OF RESIDENT POPULATION ..................          275. PERSONS.
```

TABLE 5.8 (cont.)

SUMMARY RESULTS FOR GRID ELEMENT 14

```
****************************************************************
* MULTIPLY $'s, AREAS AND MAN/EQUIP-HOURS BY:     1.000E+03*
****************************************************************
```

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING	1.0000.
RADIATION LIMIT FOR ORGAN 1 IS	10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........	30
OPTIMAL TIME TO DECONTAMINATE IS IN YEAR......	4 ←
ANNUAL DEPRECIATION FACTOR IS.................	.10
DISCOUNT FACTOR IS............................	.10
DISCOUNT FOR RESIDUAL CONTAMINATION IS........	.10
TOTAL DECONTAMINATION COSTS ARE.............. $	9573.
TOTAL AREA DECONTAMINATED IS..................	3896.0 SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $	2.46
AREA REQUIRING NO DECONTAMINATION IS..........	780.7 SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....	.0 SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS .... $	61738.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $	55564.
NET PRESENT VALUE OF PROPERTY IS .... $	18361.
TOTAL REDUCTION IN PROPERTY VALUE IS .... $	43376.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS	44.291 MAN-REM.
SIZE OF RESIDENT POPULATION	333. PERSONS.

SUMMARY RESULTS FOR GRID ELEMENT 15

```
****************************************************************
* MULTIPLY $'s, AREAS AND MAN/EQUIP-HOURS BY:     1.000E+03*
****************************************************************
```

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING	1.0000.
RADIATION LIMIT FOR ORGAN 1 IS	10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........	30
OPTIMAL TIME TO DECONTAMINATE IS IN YEAR......	3 ←
ANNUAL DEPRECIATION FACTOR IS.................	.10
DISCOUNT FACTOR IS............................	.10
DISCOUNT FOR RESIDUAL CONTAMINATION IS........	.10
TOTAL DECONTAMINATION COSTS ARE.............. $	10621.
TOTAL AREA DECONTAMINATED IS..................	4994.0 SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $	2.13
AREA REQUIRING NO DECONTAMINATION IS..........	958.3 SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....	.0 SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS .... $	79347.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $	71412.
NET PRESENT VALUE OF PROPERTY IS .... $	31133.
TOTAL REDUCTION IN PROPERTY VALUE IS .... $	48214.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS	44.517 MAN-REM.
SIZE OF RESIDENT POPULATION	371. PERSONS.

TABLE 5.8 (cont.)

```
     [illegible]  FOR GRID ELEMENT   16

***************************************************************
* MULTIPLY $'S, AREAS AND MAN/EQUIP-HOURS BY:     1.000E+03*
***************************************************************

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING    1.0000.
RADIATION LIMIT FOR ORGAN 1 IS ...............       10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........          30
OPTIMAL TIME TO DECONTAMINATE IS IN YEAR......           1<--
ANNUAL DEPRECIATION FACTOR IS.................         .10
DISCOUNT FACTOR IS............................         .10
DISCOUNT FOR RESIDUAL CONTAMINATION IS........         .10
TOTAL DECONTAMINATION COSTS ARE.............. $    109251.
TOTAL AREA DECONTAMINATED IS.................      43425.0 SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $       2.52
AREA REQUIRING NO DECONTAMINATION IS.........      12725.7 SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....           .0 SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS .............. $    661227.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $    595104.
NET PRESENT VALUE OF PROPERTY IS ............ $    387584.
TOTAL REDUCTION IN PROPERTY VALUE IS ........ $    273642.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS ......     578.276 MAN-REM.
SIZE OF RESIDENT POPULATION ..................       9043. PERSONS.
```

five grid elements plus number 11 are closest to the release point and along the plume centerline.

Grid element 11, which borders the release point, could not be decontaminated within 30 years of the release time using decontamination methods currently available in the reference database. Grid element 12 can be decontaminated; the results indicate waiting until the 13th year, however, to minimize the property losses. The summary table for this grid element also shows that the net present value of the property immediately following the accident is only $485,000, compared with a pre-accident value of nearly $26.5 million. This result is based on a discount rate of 10 percent, an annual depreciation factor of 10 percent and discount of 10 percent due to residual contamination. The first two factors operating for a 13-year period sharply reduce the present worth of the property.

The summary results for grid element 13 indicate waiting 6 years from the time of release to decontaminate. Decontamination costs of $7.1 million are still only a small part of the total property losses of over $36 million. In grid elements 14, 15, and 16 decontamination should be scheduled for years 4, 3 and 1, respectively, to minimize property losses.

Just as one would expect, the average decontamination costs tend to decline the further one gets from the point of release. These costs, measured in dollars per square meter, are $2.61, $2.53, $2.46, $2.13 and $2.52, for grid elements 12 through 16, respectively. (Average costs drop to $.72 per square meter in grid element 17.) We shall consider these costs more closely when we examine a grid element in greater detail.

In nearly all cases, the decontamination costs constitute only a small fraction of the total property losses. This suggests that decontamination activities are scheduled just as soon after the accident as possible; i.e., as soon as the methods in the reference data base allow all surfaces within the grid element to be decontaminated. (It is recalled that DECON applies the rule that all surfaces within a grid element are decontaminated at the same time, or none are decontaminated.) This means that cost effectiveness could probably be enhanced by including even more costly methods in the reference data base provided that they are more effective than existing methods.

The summary results also show the whole body external dose to radiation workers. The calculation assumes that all of the decontamination is conducted within the scheduled year. In the current implementation of DECON, radiation workers include workers engaged directly in decontamination activities. There are plans to include workers involved in surveying and monitoring activities as well. From grid elements 12 through 16, doses to workers are 27.4, 37.0, 44.3, 44.5 and 578.3 man-rem. The doses rise as one gets further from the release point for two reasons: 1) the land area within each grid element is increasing substantially, and 2) decontamination of the grid elements closer to the release point is deferred for a number of years, thus reducing the exposure.

The final entry shows the number of persons resident in grid elements 1 thru 30 at the time of the accident--about 2.5 million. We turn now to looking at a single grid element in considerable detail.

5.2.3 Micro-Analysis of a Grid Element

Summary results for grid element 15 were presented in Table 5.8. We now examine the decontamination of this grid element in greater detail. These results are presented in Table 5.9. The surface being treated is identified in the first column of the table. In the next column is given the surface area in thousands of square meters. The next column, labeled "dose", gives the 70-year dose commitment in rem. In the fourth column, "ATDF" denotes the adjusted target decontamination factor. The target decontamination factor is the minimum factor that must be achieved to meet the imposed cleanup criterion. Adjustments to the target decontamination factor are made for the reduced amount of contaminants on vertical, exterior walls and on interior surfaces. The symbolic expression for the decontamination method is given in the next column. Each letter component of the method is defined in Table 1.1. The decontamination factor, DF, associated with that method is given in column 6. In column 7, is the cost of the method in dollars per square meter, followed in the next column by the total cost to decontaminate the surface. The final column gives the rate at which the surface can be decontaminated using the indicated method and is measured in square meters per hour.

For the most part this grid element can be decontaminated using relatively inexpensive methods three years after release. Agricultural fields are plowed and then covered with 6" of soil at a cost of $1.21 per square meter. Eighty-four cents of this amount is the cost of hauling in the soil. Vacant lands are plowed at a unit cost of only $.0280 per square meter. Wooded lands are a problem area. First, they are treated with a fixative, then the land is cleared of all trees and about a foot of topsoil is removed. This operation costs $8.83 per square meter. However, about $4 per square meter represents the wealth loss from prematurely removing the trees. The total cost of treating 857,000 square meters of wooded land--about a third of a square mile--is over $7.5 million.

Exterior and interior walls do not require decontamination. Interior floors require treatment, however. All floor surfaces are vacuumed, and carpeted surfaces receive a foam treatment as well. Costs vary from $.27 per square meter for linoleum and wood floors to $1.23 for carpeted floors.

Asphalt and concrete streets, roads and other paved surfaces receive a foam treatment at under ten cents a square meter. Roofs receive a low pressure wash preceded by a vacuuming at $.46 per square meter, and four applications of water are given to lawns at $.056 per square meter.

The current implementation of DECON is not based on the number of automobiles that require treatment. The primary reason for this is that the private automobile will be the principle means of evacuation, and the number likely to remain in the contaminated area has not been determined. Therefore, we provide the information for treating a "unit" of automobiles, where a unit is defined

TABLE 5.9 Micro-Analysis of Grid Element 15

DETAILED SURFACE RESULTS FOR GRID ELEMENT 15

*** RAIN ***

PROB. OF RAIN/SNOW BEFORE DECONTAMINATING... 1.0000.

SURFACE	AREA	DOSE	ATDF	METH	DF	COST/M**2	TOT. COST	RATE
AGRICULTURAL FIELDS	2036	76.96	7.7	AG	11.1	1.2120	2467.87	549
VACANT LAND	796	76.96	7.7	A	20.0	.0280	22.29	1770
WOODED LAND	857	76.96	7.7	TNx	9.3	8.8260	7571.97	266
EXTERIOR WOOD WALLS	102	7.70	.8	----	....	....	....	.....
EXTER'R BRICK WALLS	215	7.70	.8	----	....	....	....	.....
LINOLEUM FLOORS	174	38.48	3.8	V	20.0	.2700	47.11	69
WOOD FLOORS	25	38.48	3.8	V	6.7	.2700	6.90	69
CARPETED FLOORS	117	38.48	3.8	VF	4.0	1.2300	144.72	40
CONCRETE FLOORS	151	38.48	3.8	v	4.7	.5400	81.86	69
INT'R WOOD/PL WALLS	526	3.85	.4	----	....	....	....	.....
INT'R CNCRETE WALLS	113	3.85	.4	----	....	....	....	.....
ASPHALT STRTS/PRKNG	202	76.96	7.7	F	10.0	.0911	18.40	17186
CNCRETE STRTS/PRKNG	175	76.96	7.7	F	10.0	.0911	15.97	17186
ROOFS	242	76.96	7.7	VW	8.0	.4600	111.45	81
LAWNS	207	76.96	7.7	WWWW	8.4	.0560	11.60	1302
AUTO EXTERIORS	1	76.96	7.7	TWW	14.3	60.0000	60.00	1
AUTO INTERIORS	1	76.96	7.7	v	9.5	10.0000	10.00	3
AUTO TIRES	1	76.96	7.7	S	8.3	12.7100	12.71	8
AUTO ENG/DRV TRAIN	1	76.96	7.7	E	10.0	36.9000	36.90	1
OTHR PAVED ASPHALT	2	76.96	7.7	F	10.0	.0995	.29	8593
OTHR PAVED CNCRETE	11	76.96	7.7	F	10.0	.0995	1.17	8593

NOTES:

= QUICK-VAC IN EFFECT + = REQUIRED METHOD ~ = QUICK-VAC + REQUIRED METHOD
/ = RESTRICTED OPERATION(S) * = QUICK-VAC + RESTRICTED OPERATION(S)
//// = UNABLE TO DECONTAMINATE SURFACE ---- = DECONTAMINATION NOT REQUIRED

TOTAL FACTOR INPUT REQUIREMENTS
(MAN/EQUIPMENT HOURS)

DRIVER, HEAVY TRUCK	10.41
OPERATOR, MED. EQUIPMENT	27.21
OPERATOR, LIGHT EQUIPMENT	.13
OPERATOR, FARM EQUIPMENT	.69
BUILDING LABORER	18.63
COMMON LABORER	1.67
CLEANING WORKER	12.20
FOREMAN	5.84
PILOT	.17
FLIGHT CREWMAN	.17
AIR GROUND CREWMAN	.34
SPRAY OPERATOR	2.94
FRONT END LOADER	10.98
BULLDOZER	3.71
AIRPLANE	.17
TRACTOR W/PLOW	.69
CHIPPING MACHINE	3.23
HYDRAULIC EXCAVATOR	3.24
VACUUM, HAND	11.37
PAINT SPRAY EQUIPMENT	2.94
VACUUMIZED STREET SWEEPER	.02
SANDBLAST EQUIPMENT	.13
TOW TRUCK	1.00
GRADER	2.62
VEHICLE WASHING EQUIPMENT	.50
DUMP TRUCK	9.41
SMALL TANK-SPRAY TRUCK	.02

as one automobile times the scale factor. In the present case a unit is 1,000 autombiles.

The treatment of automobile exteriors includes the cost of towing the automobile to a decontamination facility. There is a $50 charge per automobile for this. The exterior of each car then receives a double wash for an additional $10 per car. Automobile interiors receive a double vacuum for $10 and the tires are sandblasted for another $12.71. Finally, the engine and drive train are cleaned in a solvent for $36.90.

The lower panel in Table 5.9 reports the man-hours and equipment-hours, by type of physical input, required to decontaminate this grid element. Input requirements range from 27,200 hours of medium-equipment operators to just 20 hours of a small tank-spray truck.

5.2.4 Restrictions on Specific Operations

DECON can also be applied to all or part of an area in which certain operations are restricted. In the present study, we demonstrate this feature by prohibiting the use of water while decontaminating exterior surfaces. Contaminated water has the potential of creating major problems. It can penetrate the root systems of plants, crops and trees, and it can contaminate sewage systems and water treatment facilities. The benefits from using water--an inexpensive and effective way to reduce exposure through external and inhalation pathways--must therefore be carefully weighed against the costs.

The results of running DECON with a ban on operations using water are presented in Table 5.10. With a ban on the use of water on exterior surfaces, decontamination costs increase to $344.6 million, from $325 million in the base case. A comparison of the bottom panel in Table 5.10 with the bottom panel in Table 5.7 reveals which surfaces account for the increased costs. For example, in the base case 8,090 square meters of vacant land were treated with water and 25,343 were plowed. With water prohibited, 32,990 square meters are plowed and 529 square meters are not decontaminated.

5.2.5 Required Method

Table 5.11 shows a case in which we pre-specify the method that is to be used on a particular surface. In the present case, we require a single application of water on agricultural fields. Note that even though the decontamination factor for this method is less than the adjusted target decontamination factor, the method is still included because it was required by the user. Although not shown, the method that was previously selected for this surface was plowing followed by a 6" covering of fresh soil. This latter method costs $280,000 versus $5,000 for the less effective watering method.

5.2.6 Varying Exposure Factors

Another application of DECON is to allow the cleanup standards to be adjusted according to the type of surface. The potential usefulness of this feature lies in the fact that human exposures to different surfaces vary

TABLE 5.10 Decontamination Without Water

SUMMARY RESULTS FOR EXPOSURE AREA 1 TO EXPOSURE AREA 14

```
**********************************************************
* MULTIPLY $'s, AREAS AND MAN/EQUIP-HOURS BY:    1.000E+03*
**********************************************************
```

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING		1.0000.
RADIATION LIMIT FOR ORGAN 1 IS		10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........		30
TOTAL DECONTAMINATION COSTS ARE..............	$	344620.
TOTAL AREA DECONTAMINATED IS.................		507039.0 SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE.......	$	.68
AREA REQUIRING NO DECONTAMINATION IS.........		2079104.0 SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....		4009.9 SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS	$	40798520.
POST-DECONTAMINATION PROPERTY VALUE IS	$	36718670.
NET PRESENT VALUE OF PROPERTY IS	$	35598450.
TOTAL REDUCTION IN PROPERTY VALUE IS	$	5200072.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS		3325.832 MAN-REM.
SIZE OF RESIDENT POPULATION		2523837. PERSONS.

TOTAL FACTOR INPUT REQUIREMENTS
(MAN/EQUIPMENT HOURS)

DRIVER, HEAVY TRUCK	423.51
OPERATOR, MED. EQUIPMENT	1700.31
OPERATOR, LIGHT EQUIPMENT	4.13
OPERATOR, FARM EQUIPMENT	23.01
BUILDING LABORER	398.27
COMMON LABORER	258.23
CLEANING WORKER	1036.72
FOREMAN	157.17
PILOT	5.82
FLIGHT CREWMAN	5.82
AIR GROUND CREWMAN	11.63
SPRAY OPERATOR	49.67
FRONT END LOADER	264.42
BULLDOZER	31.71
AIRPLANE	5.82
ORCHARD BLAST SPRAYER	.17
TRACTOR W/PLOW	22.84
CHIPPING MACHINE	71.49
HYDRAULIC EXCAVATOR	67.00
VACUUM, HAND	888.39
PAINT SPRAY EQUIPMENT	49.67
VACUUMIZED STREET SWEEPER	5.69
SANDBLAST EQUIPMENT	.13
TOW TRUCK	12.00
GRADER	85.68
VEHICLE WASHING EQUIPMENT	51.00
DUMP TRUCK	411.51
SMALL TANK-SPRAY TRUCK	1.12
ENGINE STEAM CLEANER	4.00

TABLE 5.10 (cont.)

TOTAL AREA DECONTAMINATED, BY SURFACE AND METHOD

SURFACE TYPE	METHOD	AREA (SQ. METERS)
AGRICULTURAL FIELDS	X	27691.
AGRICULTURAL FIELDS	A	18230.
AGRICULTURAL FIELDS	AG	17408.
AGRICULTURAL FIELDS	NOT DECONTAMINATED	1354.
VACANT LAND	A	32990.
VACANT LAND	NOT DECONTAMINATED	529.
WOODED LAND	TNX	11677.
WOODED LAND	TNx	7334.
WOODED LAND	TDh	965.
WOODED LAND	TX	9093.
WOODED LAND	NOT DECONTAMINATED	570.
EXTERIOR WOOD WALLS	NOT DECONTAMINATED	72.
EXTER'R BRICK WALLS	NOT DECONTAMINATED	144.
LINOLEUM FLOORS	V	12514.
LINOLEUM FLOORS	NOT DECONTAMINATED	117.
WOOD FLOORS	V	9570.
WOOD FLOORS	NOT DECONTAMINATED	18.
CARPETED FLOORS	V	20178.
CARPETED FLOORS	v	234.
CARPETED FLOORS	VF	75.
CARPETED FLOORS	vF	1911.
CARPETED FLOORS	NOT DECONTAMINATED	81.
CONCRETE FLOORS	V	8899.
CONCRETE FLOORS	v	1652.
CONCRETE FLOORS	NOT DECONTAMINATED	102.
INT'R WOOD/PL WALLS	NOT DECONTAMINATED	358.
INT'R CNCRETE WALLS	NOT DECONTAMINATED	77.
ASPHALT STRTS/PRKNG	V	12165.
ASPHALT STRTS/PRKNG	F	4447.
ASPHALT STRTS/PRKNG	NOT DECONTAMINATED	134.
CNCRETE STRTS/PRKNG	V	10420.
CNCRETE STRTS/PRKNG	F	3860.
CNCRETE STRTS/PRKNG	NOT DECONTAMINATED	117.
ROOFS	V	55001.
ROOFS	H	32170.
ROOFS	NOT DECONTAMINATED	164.
LAWNS	R	5554.
LAWNS	L	189120.
LAWNS	NOT DECONTAMINATED	146.
AUTO EXTERIORS	NOT DECONTAMINATED	4.
AUTO INTERIORS	NOT DECONTAMINATED	4.
AUTO TIRES	NOT DECONTAMINATED	4.
AUTO ENG/DRV TRAIN	NOT DECONTAMINATED	4.
OTHR PAVED ASPHALT	V	1680.
OTHR PAVED ASPHALT	F	1092.
OTHR PAVED ASPHALT	NOT DECONTAMINATED	2.
OTHR PAVED CNCRETE	V	6726.
OTHR PAVED CNCRETE	F	4383.
OTHR PAVED CNCRETE	NOT DECONTAMINATED	8.

TABLE 5.11 Decontamination With Water Specified for Agricultural Fields

DETAILED SURFACE RESULTS FOR GRID ELEMENT 1

*** RAIN ***

PROB. OF RAIN/SNOW BEFORE DECONTAMINATING... 1.0000.

SURFACE	AREA	DOSE	ATDF	METH	DF	COST/M**2	TOT. COST	RATE
AGRICULTURAL FIELDS	231	85.36	8.5	W	1.9	.0219	5.07	0
VACANT LAND	90	85.36	8.5	A	20.0	.0280	2.53	1770
WOODED LAND	97	85.36	8.5	TNx	9.9	8.8260	861.06	266
EXTERIOR WOOD WALLS	7	8.54	.9	----	....	....	....	.....
EXTER'R BRICK WALLS	23	8.54	.9	----	....	....	....	.....
LINOLEUM FLOORS	18	42.68	4.3	V	20.0	.2700	5.12	69
WOOD FLOORS	1	42.68	4.3	V	6.7	.2700	.54	69
CARPETED FLOORS	11	42.68	4.3	vF	4.6	1.5000	17.02	40
CONCRETE FLOORS	16	42.68	4.3	v	4.7	.5400	8.91	69
INT'R WOOD/PL WALLS	53	4.27	.4	----	....	....	....	.....
INT'R CNCRETE WALLS	11	4.27	.4	----	....	....	....	.....
ASPHALT STRTS/PRKNG	22	85.36	8.5	F	10.0	.0911	2.09	17186
CNCRETE STRTS/PRKNG	19	85.36	8.5	F	10.0	.0911	1.82	17186
ROOFS	24	85.36	8.5	WW	26.7	.4600	11.41	81
LAWNS	16	85.36	8.5	R	50.0	6.0438	97.61	40
AUTO EXTERIORS	1	85.36	8.5	TWW	14.3	60.0000	60.00	1
AUTO INTERIORS	1	85.36	8.5	v	9.5	10.0000	10.00	3
AUTO TIRES	1	85.36	8.5	R	1000.0	225.0000	225.00	1
AUTO ENG/DRV TRAIN	1	85.36	8.5	E	10.0	36.9000	36.90	1
OTHR PAVED ASPHALT	0	85.36	8.5	F	10.0	.0995	.02	8593
OTHR PAVED CNCRETE	0	85.36	8.5	F	10.0	.0995	.09	8593

NOTES:

\# = QUICK-VAC IN EFFECT + = REQUIRED METHOD ~ = QUICK-VAC + REQUIRED METHOD
/ = RESTRICTED OPERATION(S) * = QUICK-VAC + RESTRICTED OPERATION(S)
//// = UNABLE TO DECONTAMINATE SURFACE ---- = DECONTAMINATION NOT REQUIRED

TABLE 5.11 (cont.)

SUMMARY RESULTS FOR GRID ELEMENT 1

```
*********************************************************
* MULTIPLY $'s, AREAS AND MAN/EQUIP-HOURS BY:    1.000E+03*
*********************************************************
```

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING		1.0000.	
RADIATION LIMIT FOR ORGAN 1 IS		10.00	
NUMBER OF TIME PERIODS CONSIDERED IS..........		30	
OPTIMAL TIME TO DECONTAMINATE IS IN YEAR......		8	
ANNUAL DEPRECIATION FACTOR IS.................		.10	
DISCOUNT FACTOR IS...........................		.10	
DISCOUNT FOR RESIDUAL CONTAMINATION IS........		.10	
TOTAL DECONTAMINATION COSTS ARE..............	$	1345.	
TOTAL AREA DECONTAMINATED IS.................		545.0	SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE.......	$	2.47	
AREA REQUIRING NO DECONTAMINATION IS.........		96.8	SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....		.0	SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS	$	8840.	
POST-DECONTAMINATION PROPERTY VALUE IS	$	7956.	
NET PRESENT VALUE OF PROPERTY IS	$	970.	
TOTAL REDUCTION IN PROPERTY VALUE IS	$	7870.	
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS		10.452	MAN-REM.
SIZE OF RESIDENT POPULATION		29.	PERSONS.

TOTAL FACTOR INPUT REQUIREMENTS
(MAN/EQUIPMENT HOURS)

DRIVER, HEAVY TRUCK	2.03
OPERATOR, MED. EQUIPMENT	2.65
OPERATOR, FARM EQUIPMENT	.05
BUILDING LABORER	1.76
COMMON LABORER	2.67
CLEANING WORKER	2.78
FOREMAN	.66
PILOT	.02
FLIGHT CREWMAN	.02
AIR GROUND CREWMAN	.04
SPRAY OPERATOR	.28
FRONT END LOADER	.96
5000 GAL SPRAY TRUCK W/PUMP&BOOM	.11
AIRPLANE	.02
TRACTOR W/PLOW	.05
CHIPPING MACHINE	.37
HYDRAULIC EXCAVATOR	.37
VACUUM, HAND	1.94
PAINT SPRAY EQUIPMENT	.28
TOW TRUCK	1.00
GRADER	.30
VEHICLE WASHING EQUIPMENT	.50
DUMP TRUCK	.92

considerably. Housing interiors, for example, would usually give high exposures while highways and wooded areas would tend to offer lower exposures. The exposure factors are defined as being inversely proportional to the target decontamination factors, and with values in the base case equal to 1.0. Thus, an exposure factor of 2.0 means that it would be necessary to remove from a surface just half of the contaminants that would be required with an exposure factor of 1.0. To illustrate this feature, DECON was run with the exposure factors shown in Table 5.12.

Total decontamination costs fall to $229 million when the exposure factors in Table 5.12 are used, compared with $325 million in decontamination costs in the base case. Furthermore, all of the surfaces could be decontaminted with methods currently in the reference database. Under the base case, grid element 11 could not be decontaminated. A comparison of the net present values of the property for grid elements 11 through 18 is presented in Table 5.13. Varying

TABLE 5.12. Selected Exposure Factors

Surface	Exposure Factor	Surface	Exposure Factor
Agricultural Fields	1.0	Streets/Parking, Asphalt	6.0
Orchards	4.0	Streets/Parking, Concrete	6.0
Vacant Land	10.0	Wooded Land	10.0
Exterior Walls, Wood	1.5	Exterior Walls, Brick	1.5
Floors, Linoleum	0.5	Floors, Wood	0.5
Floors, Carpeted	1.5	Floors, Concrete	1.5
Interior Walls, Painted	0.5	Interior Walls, Concrete	1.5
Roofs	1.0	Lawns	1.3
Auto Interiors	0.9	Auto Exteriors	2.0
Auto Engine/Drive Train	1.6	Auto Tires	5.0
Other Paved Surfaces, Asphalt	1.0	Other Paved Surfaces, Concrete	1.0

TABLE 5.13. Net Present Value of Property Varying Exposures Versus Base Case

Grid Element Number	Net Present Values of Property	
	Varying Exposure Factors	Base Case
11	129,000	0
12	8,917,000	485,000
13	20,283,000	7,906,000
14	31,872,000	18,361,000
15	46,759,000	31,133,000
16	427,938,000	327,584,000
17	785,442,000	757,476,000
18	1,100,375,000	1,067,913,000

the exposure factors results in substantially fewer property losses. The differences are particularly striking in the grid elements closer to the point of release.

5.2.7 Cleanup Standards vs. Decontamination Costs

In this part of the analysis, DECON is used to demonstrate how one can establish the relationship between cleanup standards and decontamination costs. Up to this point the radiation limit that has been in effect is a 10-rem 70-year dose commitment. We now consider 70-year dose commitments of 1.0, 2.5, 5.0, 7.5, 15.0, 20.0, 25.0 and 40.0 rem. The results are presented in Table 5.14. They show a clear tradeoff between decontamination costs and cleanup standards or, equivalently, health risks. Decontamination costs vary from $103 million in the case of a 40-rem limit up to $2.1 billion for a 1.0 rem limit. The surface area that requires no decontamination varies from 911 million square meters in the 1.0-rem case to 2,376 million square meters in the 40-rem case.

It is also of interest to determine the effect on property values as the cleanup standard varies. We have already noted that decontamination costs are apparently a relatively minor component of the property losses. The major losses are the result of depreciation and loss of property use when decontamination must be deferred. The stricter is the cleanup standard, the more likely it is that decontamination will be deferred. Table 5.15 presents the value of property, as measured immediately following the accident, for the various cleanup standards. As expected, net present property values clearly rise as the radiation limit rises. At a 70-year dose commitment of just 1.0 rem, the net present value of property in the accident area is $21.7 billions; with a 70-year dose commitment of 40 rem, the net present value of property rises to $39.7 billions. This tradeoff between radiation limits and property losses provides the basis for an informed decision on where to set the radiation limit to protect public health while at the same time keeping down property losses.

TABLE 5.14. Cleanup Standards vs. Decontamination Costs

70-Year Dose Commitment (rem)	Total Cost ($ 000's)	Unit Cost ($/m^2)	Area Not Decontaminated (m^2) (Unable to)	(Not Required)
1.0	2,139,282	1.29	18,050,000	911,125,000
2.5	1,786,268	1.07	4,009,000	916,200,000
5.0	1,153,299	.79	2,037,000	1,132,700,000
7.5	615,694	.44	696,000	1,456,000,000
10.0	324,954	.64	696,000	2,080,300,000
15.0	209,546	.55	696,000	2,211,700,000
20.0	190,340	.73	696,000	2,328,000,000
25.0	136,613	.64	0	2,376,500,000
40.0	103,021	.48	0	2,376,500,000

TABLE 5.15. Cleanup Standards vs. Net Present Value of Property

70-Year Dose Commitment (rem)	Net Present Value ($ mill's)
1.0	$21,714
2.5	27,446
5.0	28,729
7.5	29,310
10.0	35,640
15.0	38,113
20.0	39,629
25.0	39,692
40.0	39,738

5.2.8 Conclusions

We have used DECON to explore several strategies for restoring a large site following a major reactor accident. In particular, it has been used to determine the cost-effectiveness of various actions, ranging from restricting the use of methods, through varying allowable exposure rates from different surfaces, to setting the radiation standard itself. The results are apparently particularly sensitive to the discount factor used to evaluate the loss of use of property and the depreciation rate. Losses due to residual contamination may also be substantial.

One potential use of DECON that has not been mentioned thus far is to identify specific situations that are causing inordinately large losses, and then to use this information to find mitigating actions. For example, we observed that the inability to effectively decontaminate wooded areas meant that substantial property losses occur under the rule that all of the property within a grid element is decontaminated at the same time, or none of it is. Because these wooded areas caused long delays in restoring the property within some grid elements and therefore caused substantial property losses, two alternatives are suggested. First, we might want to cordon off the wooded area for several years while allowing the surrounding property to be decontaminated and used; or we might want to expend some resources searching for more effective ways to decontaminate wooded areas. This example illustrates just one of many types of "bottlenecks" that can be found using DECON.

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APPENDIX A

A.0 INTRODUCTION

This appendix describes several procedures that can be used to decontaminate radiologically contaminated surfaces. Property types such as roads, commercial property, and residential property are decomposed into their constituent surfaces. For each surface we define several alternative decontamination operations. These operations form the basic building blocks for developing a decontamination strategy. Accordingly, this appendix presents extensive data on the operations for the decontamination of surfaces. Specifically, the following information on operations is presented:

- description
  - how the operation is performed
  - limitations and restrictions on the operation's effectiveness
  - special considerations
- rate at which operation can be accomplished (m^2/hr)
- cost of the operation ($/$m^2$)
  - total
  - labor
  - equipment
  - materials
  - other (e.g., fuel)
- input requirements
  - labor
  - equipment
  - materials
- sources of information

It is important to recognize that it may be desirable to repeat an operation or to successively use different operations on the same surface. The term "methods" is used in this report to define such combinations of one or more operations. When operations are combined, however, the first operation of the method usually has the effect of reducing the effectiveness of subsequent operations. This means that decontamination efficiencies must be estimated for all useful methods. Methods and their efficiencies are presented in Appendix B.

There are two general approaches to estimating the cost of a particular operation. The first is to construct the cost from information about the production function--i.e., the relationship between physical inputs and output(s)--and the various input prices. The second approach establishes, from people actually performing the operation, how much it costs them to perform the operation. Both approaches have problems. In the first, one runs the risk of overlooking an important input or otherwise mis-specifying the production function. The second method may yield misleading results if the sources are subject to some special conditions such as a particular constraint, regulation, or subsidy, or if the source enjoys any substantial market power.

Where possible, we tried to establish cost and productivity data by the second method. We contacted sources which provide or hire the operations in which we were interested. Of course, several of the operations apply only to radiological decontamination; they are not, therefore, customarily supplied in the marketplace. In those cases we had to resort to estimating a crude production function, and we calculated average costs using collected costs of inputs. Throughout, when specific labor costs were not available, we usually assumed the hourly cost for labor to be $17.45 per hour. This is the hourly billing cost for common building laborers reported in Means Construction Costs Data 1981. This figure includes benefits, administrative overhead, and profit. Other rates were used when the required level of skill was high. To the extent that this labor cost figure is too high or too low, the cost figures and input shares of cost reported should be adjusted accordingly.

We also gathered information about the major inputs and their respective shares of the total cost. Assuming fixed proportions of inputs and constant input cost with increasing scale of production gives a basis for estimating input requirements for the various decontamination activities.

Another important point with respect to generating representative cost estimates is the fact that different inputs are priced in different units. For instance, cost data on street sweepers are stated in terms of dollars per month or dollars per year, rather than in dollars per mile of pavement swept. The question that this issue raises is how to convert cost stated in terms of, say, dollars per month to dollars per square meter. This becomes particularly important when capital equipment constitutes a large share of costs. Operating the equipment for two shifts instead of one will spread out the daily cost over twice as many square meters, lowering the average cost per square meter. In most cases, when this issue arose, two shifts of operation per day were assumed.

One related point is that throughout the report, unit costs and production rates were adjusted to account for the reduced productivity resulting from the special conditions of working in a radioactively contaminated environment. In particular, we assumed that one hour of productive work out of every eight-hour shift was lost due to such things as the necessity of working in cumbersome protective clothing and periodic personnel and equipment contamination. The cost of this extra hour, therefore, results in a higher cost per square meter. In situtations involving severe contamination, this extra hour may still be inadequate, necessitating appropriate adjustments to the data.

Some operations involve two or more distinct steps. For example, resurfacing paved roads requires first that the surface be planed and second that a layer of asphalt be applied. It is frequently the case that the constituent procedures of an operation have different hourly production rates.

The rule for combining procedures of different rates is to make the rate of the total operation equal to the rate of the procedure with the highest cost per square meter. Doing this generally requires that more or less than one crew for other procedures be used.

All costs in this manual are in 1982 dollars. Future use of these figures may require adjustments to account for the effects of changes in the overall price level (inflation).

A.1 ASPHALT ROADS

A.1.1 Mobile Vacuumized Street Sweeping

While other operations have greater decontamination effectiveness, the cost per square meter of vacuuming is so low in comparison that it would likely be used alone or in conjunction with other procedures in essentially all instances in which pavement decontamination activities are undertaken. There are four basic types of mobile street sweepers in use by cities, highway departments, and airports. These are the mechanical rotary-broom type, the recirculating air type, the vacuum type, and the dustless vacuum type. Within the spectrum of costs encompassed by the various pavement decontamination methods, there is relatively little difference among the costs of using these devices, and the reports from the different sources disagreed as to the ranking of the vacuum types by cost. The least effective for the purposes of radiation decontamination is the mechanical rotary-broom type. This machine is intended primarily for picking up large debris such as cans, bottles, hubcaps, and mufflers. Other machines do a better job of removing small particles and are used most commonly in dusty or sandy locales. The best machine for decontamination purposes is the dustless vacuum type - a machine most commonly used at airports for cleaning runways. Because of its high filtration at the vacuum exhaust and containment skirts underneath, this type of equipment creates little or no airborne dust which could recontaminate neighboring areas.

Unlike some decontamination procedures, vacuumized street sweeping is a common operation. Therefore, it is relatively easy to get fairly reliable cost estimates by using information provided by municipal public works departments and other users of vacuumized street sweepers. The estimates obtained ranged from \$0.0020 to \$0.0057 per square meter.

The estimates of the cost per square meter are directly tied to the average vehicle operating speed. Users reported a wide range of average speeds - from 1.42 miles per hour to 10 miles per hour. Manufacturers claim effective operation for some models at speeds as high as 15 miles per hour. Actual operating rates are determined by such factors as volume of material collected per unit pavement area, the time necessary to dump collected material, the power of the vacuum, the type of material to be picked up, and the desired cleanliness to be attained. These factors suggest that subsequent vacuumings will be less costly than the first. There will be a smaller volume of material to be picked up, and the material which is picked up is less likely to include branches and other objects which can jam the intake ducts. Even if the vehicles operate at the same average speed while vacuuming, fewer trips to the dump site will be required per hour and thus total productivity will be higher. Despite the cost difference for subsequent vacuumings, data limitations precluded deriving separate estimates for the different surface treatments.

Vacuumized street sweeping requires a mobile vacuum street sweeper and a driver. Other inputs include such things as fuel, filters, brooms, and maintenance. For purposes of radiation decontamination, it may be helpful to use a sweeping compound. Maintenance is apparently a major expense, and equipment reliability is not very high. Some sources reported that this equipment required as much as one hour maintenance for every three hours operation. The information collected indicated that labor comprised anywhere from 18.5 to 60 percent of sweeping costs. A reasonable estimate based on the more reliable of these figures is that labor comprises 50 percent of vacuuming costs. The remaining costs are for equipment (15 percent), maintenance (25 percent), and fuel (10 percent).

Several factors bear on the effectiveness of vacuumized street sweeping as a decontamination technique. Small particles (diameter less than 10 microns) tend to lodge themselves in surface irregularities and thereby become more difficult to remove than larger particles. The size distribution of particles resulting from a reactor accident is likely to have relatively heavy concentrations of particles in the 1 to 10 micron range (U.S. Nuclear Regulatory Commission 1975). Further, the longer the time between initial exposure and vacuuming, the more difficult will be particle removal, as particles will have become more deeply embedded in the surface. Surface irregularities, both of microscopic and macroscopic sizes, will reduce vacuum effectiveness. The available information on the effectiveness of mobile vacuuming is scant, the best being Radiological Reclamation Performance Summary Vol. II (Owen et al. 1967). Removal efficiencies were also reported by other researchers (Horan et al. 1970; Julin et al. 1978; Wallace et al. 1975; The Product Information Network 1982), spanning a range of from 32 to 98 percent. Further, these sources did not provide any detail as to particle size or the velocity of the mobile vacuum.

Most street sweepers in use are the mechanical rotary-broom type, and while several cities that use vacuum-type sweepers were contacted, only a few of these kept adequate records from which cost per square meter could be calculated. Some cities, such as Walla Walla and Spokane in Washington, use vacuum street sweepers and keep good records, but since street flushing and vacuuming operations and records are combined, it was impossible to identify the respective shares of each.

The City of Kennewick, Washington, uses a vacuumized street sweeper. The interdepartmental rental rate which the Street Department is charged for the vehicle by the equipment pool is $2,600 per month. This covers capital, maintenance, depreciation, fuel, and so forth. To convert this monthly charge to a dollars-per-square-meter figure, we need to estimate the number of hours of operation per month and the average hourly rate of sweeping. The main factor affecting the number of hours worked per month is the number of shifts. With two shifts per day, as opposed to one, the monthly equipment cost can be spread out over twice as many hours and twice the sweeping area. At 176 hours per month for a single shift, the equipment cost is \$14.77 per hour. With two shifts per day, the equipment cost is halved, falling to \$7.385 per hour.

The labor cost reported was \$10.64 per hour plus 35 percent for benefits and administrative overhead, bringing the total labor cost to \$14.36 per hour.

There was considerable uncertainty in establishing a production rate for Kennewick street sweeping, since the Street Department keeps no mileage records. They did indicate that there were 140 street miles in the city, meaning a total of 280 potential production curb-miles. However, not all streets are swept. A total of 250 production miles in the city is a reasonable estimate. These can all be swept in a month if there is no heavy loading of debris as occurs with leaves in the fall. Coverage of 250 miles in the 176 working hours of a month works out to 11.36 miles per shift or 1.42 miles per hour. This is a particularly low speed compared with those reported by other sources. It is also much lower than the top operating speed possible of 5 miles per hour. For the purpose of estimating Kennewick's cost per square meter, the rate of 1.42 miles per hour served as a lower bound for operating speed. Another estimate was derived by assuming 30 miles per shift or 3.75 miles per hour based on production rates reported by other sources.

Assuming one hour per shift is lost to special radiation protection measures, the production rate at 1.42 miles per hour is as follows:

$$1.42 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times\ 7/8 \text{ shift hrs/8-hr shift} = 4882.5 \text{ m}^2/\text{shift-hr}$$

With one shift per day, the total cost per hour is:

$$\$14.77/\text{hr for equip.} + \$14.36/\text{hr for labor} = \$29.13/\text{hr}$$

Dividing by the average hourly production rate of 4883 square meters gives a cost per square meter of \$0.0060. With two shifts per day the hourly cost would be:

$$\$7.385/\text{hr for equip.} + \$14.36/\text{hr for labor} = \$21.75/\text{hr}$$

Dividing by the hourly production rate yields an average cost of \$0.0045 per square meter.

Alternatively, at an operating speed of 3.75 miles per hour, the estimated production for a shift hour is:

$$3.75 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times\ 7/8 \text{ shift-hrs/8-hr shift} = 12{,}890 \text{ m}^2/\text{shift-hr}$$

At this rate, the cost per square meter with one shift per day is:

$$\$29.13/\text{hr} \div 12{,}890 \text{ m}^2/\text{hr} = \$0.0023/\text{m}^2$$

With two shifts per day, the cost per square meter falls to:

$21.75 ÷ 12,890 m^2/hr = $0.0017/$m^2$

The costs for the separate inputs, labor and equipment, are calculated in the same way. Table A.1.1.1 summarizes these results.

Based on these data, a cost of $0.0030 per square meter with an average production rate of 10,000 square meters per hour was selected as representative of Kennewick's street sweeping operations. Labor comprises about 64 percent and equipment about 36 percent of total costs.

TABLE A.1.1.1. Summary of Vacuumized Street Sweeping Data for Kennewick, Washington

	Rate (m^2/hr)	Cost (1982 $/$m^2$)		
		Total	Labor	Equipment
1.42 mph				
1 shift/day	4883	0.0060	0.0029	0.0030
2 shifts/day	4883	0.0045	0.0029	0.0015
3.75 mph				
1 shift/day	12,890	0.0023	0.0011	0.0011
2 shifts/day	12,890	0.0017	0.0011	0.0006
Representative				
2 shifts/day	10,000	0.0030	0.0019	0.0011

The City of Pasco, Washington uses an Elgin Whirlwind V349 street sweeper. The Public Works Department pays an interdepartmental annual rental fee of $50,700 for the sweeper. This covers all equipment-related costs such as capital, depreciation, interest, maintenance, parts, and fuel. The operator's wage is $9.56 per hour, to which should be added an additional 70 percent for benefits and administrative overhead, according to the city engineer. However, weather, equipment breakdowns, and operator time off prevent regular eight-hour per day operation. On the other hand, the equipment is occasionally operated two shifts per day. These factors make it preferable to use total yearly labor costs rather than hourly figures. Table A.1.1.2 provides this information for the last three years. Direct cost refers to total wages, and total cost represents wages plus 70 percent for benefits and administrative overhead. The figures for 1982 were estimated from data for the first nine months of the year.

Despite detailed information about total mileage, actual production miles had to be estimated. Inspection of the sweeping log for 1982 showed total miles per day ranging from about 19 to about 44. Most days showed mileages between 20 and 30. Comparing the record of engine hours on the vacuum motor to total miles driven, it was estimated that each vacuum engine hour corresponded to three production miles. In all cases this estimate resulted in production miles being somewhat less than each day's total miles as should be the case.

TABLE A.1.1.2. Yearly Labor Cost for Vacuumized Street Sweeping in Pasco, Washington

	Costs (1982 $)		
Year	Direct Cost (Wages)	Benefits and Administrative Overhead	Total Labor Costs
1980	12,292	8,604	$20,896
1981	16,564	11,595	$28,159
1982	19,437	13,609	$33,046

From February 17, 1982, to November 24, 1982, the vacuum engine logged 1415 hours. At 3 miles per hour, this equals 4,245 production miles. Over the same period there were 219 operating shifts. This yields an average 19.38 production miles per shift. For the remaining parts of 1982 we estimated 50 shifts, bringing the total shifts to 269. Multiplying by the miles per shift gives 5214 estimated production miles for 1982.

Multiplying total hourly cost for labor ($16.252) by the number of shifts (269) and by 8 hours per shift produces an estimated total labor cost of $34,974. This is somewhat more than the $33,046 listed earlier. The difference is apparently due to the operator's working at sweeping for less than 8 hours on some shifts. The total number of sweeper operator hours for the year was about 2033. The average hours per shift was about 7.55.

The following converts total vacuum miles to area, assuming an 8-foot width:

$$4245 \text{ prod. miles} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$= 16{,}675{,}718 \text{ m}^2/\text{yr}$$

Allowing for one hour out of eight for radiation decontamination gives:

$$16{,}675{,}718 \times 7/8 = 14{,}591{,}253 \text{ m}^2/\text{yr}$$

The cost per square meter is:

$$\$83{,}746 \ / \ 14{,}591{,}253 \text{ m}^2 = \$0.0057/\text{m}^2$$

Hourly production is:

$$14{,}591{,}253 \text{ m}^2 \ / \ 2033 \text{ hrs} = 7177 \text{ m}^2/\text{hr}$$

The share of costs accounted for by labor is:

$$\frac{\$33{,}046}{\$83{,}746} = 39.5\%$$

and the share for capital (including fuel, maintenance, etc.) is 60.5 percent. In other words, the cost per square meter for labor is $0.0023 and the cost per square meter for capital is $0.0034.

The Department of Public Works in San Francisco supplied detailed cost information on their street sweeping operations. Their costs by major input, in terms of production miles, are:

TABLE A.1.1.3. Street Sweeping Costs by Input for San Francisco, California

Input	Cost (1982 $/lane mi)	Percent of Total
Fuel	1.28	9.3
Maintenance and repair	2.88	21.0
Capital	1.78	13.0
Labor	7.76[a]	56.6
Total	13.70	100.0[b]

(a) Labor cost at 7.56 per mile plus $5.00 per shift. Shift differential converted to cost per mile based on 25 miles per shift.
(b) Parts do not add to 100 due to rounding.

Of the four input categories, only labor and equipment need to be adjusted for the one hour per shift for radiation control. This is accomplished by multiplying by 8/7 to give $8.87 per mile. With an eight-foot wide sweeper swath, one mile of sweeping will cover 3928 square meters. Dividing the total cost per lane mile, $15.06, by 3928 yields a cost of $0.0038 per square meter. These calculations are summarized in Table A.1.1.4.

San Francisco uses 15 Tymco recirculating air street sweepers. The operation performance standard is 25 production miles per eight-hour shift, and

TABLE A.1.1.4. Adjusted Street Sweeping Costs by Input for San Francisco, California

Input	(Cost (1982 $) $/lane mi	$/m^2	Percent of Total
Fuel	1.28	0.0003	8.5
Maintenance and repair	2.88	0.0007	19.1
Capital	2.03	0.0005	13.5
Labor	8.87	0.0023	58.9
Total	15.06	0.0038	100.0

this standard is reportedly very close to actual production mileage. The hourly production rate, adjusted for one hour per shift for radiation control, is:

$$25 \text{ mi/shift} \div 8 \text{ hrs/shift} \times 5280 \text{ ft/mi} \times 8 \text{ ft width} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times\ 7/8 \text{ hrs/shift} = 10{,}742 \text{ m}^2/\text{hr}$$

The Maintenance and Operations division of the Washington State Department of Transportation reported their street sweeping costs as follows:

TABLE A.1.1.5. Street Sweeping Costs by Input for Washington State Department of Transportation

Input	Cost (1982 \$/lane mi)
Labor	9.55
Equipment	11.82
Materials	0.15
Total	21.52

Washington uses mechanical rotary broom type sweepers. Nonetheless, their cost and productivity information is reported here since it seems to be not greatly different from other road sweeping information.

As with the San Francisco data, the labor figure must be adjusted for one hour per shift for decontamination by multiplying by 8/7. This gives the adjusted costs shown in Table A.1.1.6.

The Washington Department of Transportation defines a lane mile as having a width of 12 feet. This gives an area of 5892.48 square meters per lane

TABLE A.1.1.6. Adjusted Street Sweeping Costs by Input for Washington State Department of Transportation

Input	Cost (1982 \$)		Percent of Total
	\$/lane mi	$\$/m^2$	
Labor	10.91	0.0019	47.7
Equipment	11.82	0.0020	51.7
Materials	0.15	0.0000	0.7
Total	22.88	0.0039	100.0[a]

[a] Parts do not add to 100 due to rounding.

mile. Dividing this figure into the cost per lane mile gives a cost of \$0.0039 per square meter. Sweepers, however, have an effective sweeping width of 8 feet. It would therefore seem necessary to adjust upward the cost to reflect using an 8-foot sweeper on a 12-foot wide lane. The adjusted area of a lane mile is computed as follows:

$$8 \text{ ft wide} \times 5280 \text{ ft/mi long} \times 0.093 \text{ m}^2/\text{ft}^2 = 3928.32 \text{ m}^2/\text{lane mi.}$$

Recalculating the cost per square meter yields \$0.0058.

The average production is 1.43 lane miles per hour. After allowing for one hour per shift for radiation control, we obtain an average hourly rate of production of:

$$1.43 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 12 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times\ 7/8 \text{ production hrs/shift hr} = 7373 \text{ m}^2/\text{hr}$$

The Maintenance Section of Cal-Trans, State of California, operates a mixed vacuum and mechanical sweeper fleet. The model of vacuum sweeper used is an FMC Model 12 Sanavac. For the 1981-82 fiscal year they recorded a total 114,432 "broom-down" (production) miles and a total cost of \$4,638,773. The cost breakdown is shown in Table A.1.1.7.

These figures are considerably different from those reported by other sources. A simple gross calculation of the cost per square meter based on total production miles and total cost yields a cost per square meter of

TABLE A.1.1.7. Street Sweeping Cost Breakdown from Cal-Trans, State of California

Input	Percent
Salaries	43
Equipment	55
Material	1
Other	1
Total	100

\$0.0103. This figure is much higher than those calculated from data supplied by other sources. Further inquiry revealed that about half of the Cal-Trans sweeping miles require an escort truck as a safety feature to warn passing traffic. Also, the Cal-Trans operation must be different in other respects, as evidenced by the existence of five-person sweeping crews. Their standard crew consists of one supervisor, one lead worker, and three workers. Salaries are in the range of \$10 to \$12 per hour.

Apparently, the Cal-Trans sweeping operation entails considerably more than just mobile street sweeping. Cleanup of litter on shoulders, medians, and culverts, as well as minor road maintenance, may be involved. The problem is to adjust the Cal-Trans figures to reflect the cost of sweeping alone. A few simple, crude steps were taken to get a rough estimate for sweeping costs. The first was to divide the labor costs by five, since we are interested in a one-man, one-sweeper operation. The second step was to reduce the equipment cost to account for the unneeded escort vehicle. If the cost of an escort truck is half the cost of the sweeper, and the escort truck is used on half the sweeper miles, then the escort truck generates roughly 25 percent of the total equipment costs. Multiplying equipment costs by 0.75 yields the adjusted figure. The adjusted figures are shown in Table A.1.1.8.

TABLE A.1.1.8. Adjusted Street Sweeping Figures from Cal-Trans

Input	Cost (1982 $)
Salaries	398,934
Equipment	1,913,494
Materials	46,388
Other	46,388
Total	2,405,204

This total cost figure yields a cost per square meter of $0.0054. Making the further adjustment to labor costs to account for radiation control by multiplying by 8/7 yields the costs shown in Table A.1.1.9.

TABLE A.1.1.9. Adjusted Street Sweeping Costs by Input for Cal-Trans, State of California

Input	Cost (1982 $) $/yr	Cost (1982 $) $/m^2	Percent of Total
Labor	455,925	0.0010	18.5
Equipment	1,913,494	0.0043	77.7
Materials	46,388	0.0001	1.9
Other	46,388	0.0001	1.9
Total	2,462,195	0.0055	100.0

The costs per square meter in Table A.1.1.9 were calculated by dividing the cost per year by the area covered per year, which is:

$$114{,}432 \text{ mi/yr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$

$$= 449{,}525{,}514 \text{ m}^2/\text{yr}$$

These calculations produce a total cost per square meter of $0.0055.

Despite these adjustments, these figures are still considerably higher than those reported by other sources. In particular, the figure of 77.7

percent of total cost for equipment is quite high compared with other sweeping operations in which figures of 40-60 percent are more common. Another question results from Cal-Trans' estimate of an average sweeping speed of 7.5 miles per hour. In general, high sweeping speeds will lead to low costs per unit surface area, and this speed is the highest speed reported from the sources contacted. Using this speed and adjusting for one hour per shift in which no vacuuming is done, we get:

$$7.5 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8$$
$$= 25{,}780 \text{ m}^2/\text{hr}$$

McGraw-Hill publishes a document called PIN or Product Information Network which is compiled by the International City Management Association and the McGraw-Hill Information Systems Company. In September, 1982 the volume concerning street sweepers was revised. This document contains a general discussion of street sweeping equipment as well as providing information on prices and performance of various types of equipment.

On page 17, PIN reports an annual cost of $350 per curb mile per year for vacuumized sweeping with one pass every five days. If "one pass every five days" is interpreted to mean once a week or 50 times per year, then the cost per curb mile per pass is $350/50 = $7.00. The cost per square meter, based on an 8-foot width, is $0.0018. Multiplying by 8/7 to adjust for time for radiation control brings the cost to $0.0020 per square meter.

PIN did not provide information on the average operating speed corresponding to the cost estimate of $350 per curb mile per year. Elsewhere in the text (p.11), a speed of 2 miles per hour was described as producing "very good" results and a speed of 4 to 5 miles per hour as resulting in a good compromise between productivity and cost. If we assume an average operating speed of 2.5 miles per hour, including time for dumping collected debris, then the average decontamination coverage per shift-hour would be:

$$2.5 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ shift-hrs/hr}$$
$$= 8593 \text{ m}^2/\text{hr}$$

While PIN discussed some aspects of sweeping costs in detail, nothing was provided which would permit calculation of the respective cost shares of the various inputs into street sweeping operations.

While the Radiological Reclamation Performance Summary, Vol. II (Owen et al. 1967) did not report any cost figures, sweeping coverage rates were listed. Actual rates were adjusted downward by the authors by 15 percent to compensate for the ideal test conditions. Further, this source listed the net rates incorporating the effects of necessary overlap of successive sweeping swaths. This has the effect of reducing the effective sweeping width to about 3.5 to 4.0 feet. The actual sweeping width of the machines used was not reported. Separate results for a variety of test results for different conditions were listed. These alternate conditions included sweeper type, pavement texture, initial mass loading of contaminant, particle size, and sweeper speed. Results from test conditions that most closely replicate the conditions likely to occur in the event of a reactor accident are reproduced here in Table A.1.1.10. Coverage rates in terms of square meters per hour range from 3,962 to 18,972. This wide range encompassed all the rates reported by other sources except that for Cal-Trans. It is clear that the operating rate is not fixed by the vehicle's capabilities so much as by other factors. A major criterion might be the associated removal efficiency, but here, too, a representative rate is not immediately apparent. The conventional mechanical street sweeper achieved a first-pass removal efficiency of 62 percent for 74-177 micron-sized particles on rough pavement at the very high coverage rate of 18,972 square meters per hour. This was only nominally better than the removal efficiency reported at 5,915 square meters per hour for the same conditions. We calculated a representative rate for these tests by averaging the coverage rates for all tests for which the first-pass removal efficiency was greater than 50 percent. This yields a figure of 9732 square meters per hour.

However, the nature of the test procedures requires some further adjustments. In particular, no time was alotted for the effects on productivity for working in a radioactive environment. Also, the production rates given by this source do not include any time for dumping collected materials. Assuming that one hour per shift would account for reduced productivity resulting from the hazardous environment and that half an hour per shift would be necessary for dumping, we get an adjusted coverage rate of:

$$\frac{9732\ m^2/hr \times 6.5\ hrs}{8\ hrs} = 7907\ m^2/hr$$

Table A.1.1.11 summarizes the data on vacuumized sweeping costs. Also shown are representative rate and cost data.

The average hourly production rates from the various sources are reasonably close, except for the Cal-Trans figure. In averaging the rates to arrive at a representative hourly figure, the Cal-Trans value was ignored.

The cost data cover a broader span. While the PIN figure is quite low, it supposedly represents an average taken from several municipalities. For this reason it was included in computing the average, which is the basis for the representative cost figure.

All sources that disaggregated their costs by input groups listed labor as a separate category. However, there was considerable variation in the way that non-labor costs were categorized, making input costs hard to synthesize. The approach used here was to add all the non-labor costs together into a composite input called equipment. Representative input costs are calculated as simple averages, excluding the Cal-Trans figures. The input cost proportions reported by the San Francisco Department of Public Works could be used as a rough guide for further input cost disaggregation, if necessary.

TABLE A.1.1.10. Selected Street Sweeping Data

Sweeper Type	Pavement Texture	Particle Size (μ)	Gear	Speed (mph)	Rate		Effective Width (ft)	Pass and Marginal Removal Efficiency (%)				
					(ft^2/min)	(m^2/hr)		1	2	3	4	5
Mechanical	Rough	74-177	1	2.5	1,060	5,915	4.8	64	67	67	45	18
			2	6.0	2,130	11,885	4.0	62	64	41	10	--
			3	9.5	3,400	18,972	4.1	62	63	60	44	22
Vacuumized	Rough	44-74	1	2.5	710	3,962	3.2	64	17	--	--	--
			2	5.0	1,550	8,649	3.5	38	32	19	12	--
			3	8.0	2,430	13,559	3.5	30	26	19	14	6
Vacuumized	Smooth	44-74	2	4.5	1,420	7,924	3.6	82	64	21	--	--

Note: Initial mass loading of contaminant was five grams per square foot. Tests were performed under temperate weather conditions.

Source: Radiological Reclamation Performance Summary, Vol. II

TABLE A.1.1.11. Summary of Vacuumized Street Sweeping Cost Data

Source	Rate (m^2/hr)	Cost (1982 $/$m^2$)[a] Total	Labor	Equipment
Kennewick Street Dept.	10,000	0.0030	0.0019	0.0011
Pasco Pub. Works	7,177	0.0057	0.0023	0.0034
San Francisco Pub. Works	10,742	0.0038	0.0023	0.0015
Washington Dept. of Trans.	7,373	0.0056	0.0019	0.0020
California Cal-Trans	29,462	0.0055	0.0010	0.0045
PIN	8,593	0.0020	--	--
Owen et al.	7,907	--	--	--
Representative	8,632	0.0043	0.0021	0.0022

(a) Equipment includes all non-labor costs.

A.1.2 Low-Pressure Water Wash

Using mobile street flushers to apply a low-pressure water wash to paved surfaces is the least costly decontamination operation per square meter. Further, the decontamination efficiency of this operation is fairly high--95 percent on the first pass for pavement on which there has been no rain. However, this procedure results in a byproduct of a certain amount of contaminated water, which leads to the important question of what, if anything, to do with this water. In this section the flushing operation and the calculation of the costs of flushing per unit area will be discussed.

The City of Los Angeles calculates the average cost of mobile street flushing at $9.08 per mile for all inputs, including labor, equipment, maintenance, fuel, and so forth, including an average ten percent down time for the flushers. This cost varies with factors such as terrain; they estimate the cost per mile over flat areas at $5.68 per mile and $23.00 per mile in hilly areas. Despite this cost detail by terrain, they have no data on the costs of the different inputs.

According to this same source, the average net speed is five miles per hour. Therefore, in an average eight-hour shift the flusher will cover 40 miles. If we adjust this rate by a factor of 7/8 to account for radiation control measures, the mileage per shift is 35.

The flushers average 10 percent down time. That means for an average 8-hour shift, the flusher is available for 7.2 hours. During operation, the average speed is 5 miles per hour. Therefore, in an average 8-hour shift the flusher will cover 7.2 hours x 5 mi/hr = 36 miles. If we adjust this rate by a factor of 7/8 to account for one hour per shift for special radiation control operations and reduced productivity, the mileage per shift is 31.5.

Flushers may be configured to flush one or both sides of the street at a time. The normal practice seems to be to flush one side at a time. That is the practice adopted by Los Angeles, and it on this basis that most flushing costs were calculated in this report. While street widths vary, a reasonable average width according to this source is 40 feet. That makes the width of a flush 20 feet. The coverage per shift hour is, then:

$$35 \text{ mi/shift} \times 5280 \text{ ft/mi} \times 20 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\div\ 8 \text{ hrs/shift} = 42{,}966 \text{ m}^2/\text{shift-hr}$$

Assuming that the cost per shift will not fall in direct proportion to the drop in output due to seven rather than eight hours of production, the cost per square meter is calculated on the basis of an unchanged total cost per shift, even with only seven production hours out of eight. Therefore, the cost per shift hour is:

$$\frac{\$9.08/\text{mi} \times 40 \text{ mi/shift}}{8 \text{ hrs/shift}} = \$45.40 \text{ per hour}$$

The cost per square meter is, then

$$\$45.40/\text{hr} \div 42{,}966 \text{ m}^2/\text{hr} = \$.0011/\text{m}^2$$

The Public Works Department of the City of San Francisco provided its costs per mile for flushing, broken down by input as shown in Table A.1.2.1. The production rate is 40 lane-miles per 8-hour shift for an average 5 miles per hour. This figure includes time for refilling and breakdowns. Reducing the productivity rate by an hour per shift to account for necessary radiation control brings the average hourly speed down to 5 x 7/8 = 4.375. The average hourly production, then, is:

$$4.375 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 20 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 = 42{,}966 \text{ m}^2/\text{hr}$$

As with the Los Angeles flushing data, we again assume that per shift costs would not be reduced by the hour per shift spent on radiation control measures. The cost per square meter is therefore calculated in the following manner:

$$\frac{\$8.07/\text{mi} \times 40 \text{ mi/shift}}{42{,}966 \text{ m}^2/\text{shift hr} \times 8} = \frac{\$322.8/\text{shift}}{343{,}728 \text{ m}^2/\text{shift}} = \$0.0009/\text{m}^2$$

TABLE A.1.2.1. Flushing Costs by Input From the Public Works Department, City of San Francisco

Input	Cost (1982 $/mi)
Fuel	0.80
Maintenance and equipment	1.20
Equipment	1.00
Labor	5.07
Total	8.07

Input costs per square meter are calculated on the basis of the cost shares for the different inputs as reported by the City of San Francisco. Therefore, the estimated costs per square meter are as shown in Table A.1.2.2.

The City of Seattle Public Works Department reported that over fiscal year 1981-82 the cost of street flushing operations was $139,601. There were a

TABLE A.1.2.2. Estimated Flushing Costs from the City of San Francisco

Input	Percent of Total	Cost (1982 $/m^2)
Fuel	10	0.0001
Maintenance and repair	15	0.0001
Equipment	12	0.0001
Labor	65	0.0006
TOTAL	100	0.0009

total of 10,169 production miles, so the cost per mile averaged $13.72. The flusher is leased interdepartmentally from the city's Department of Administrative Services at $20.38 per hour. This covers fuel, maintenance, depreciation, interest, capital, and so forth. The cost of the driver, including benefits and administrative overhead, is $22.50 per hour. The cost of flusher and driver together come to $340 per shift. Output per shift is 25 miles.

Adjusting output by 7/8, we get a per-shift output of 21.875 miles. With a flush width of 20 feet, this amounts to 214,830 square meters per shift or 26,854 square meters per hour. Dividing the cost per shift by the output per shift yields a cost per square meter of $0.0016. The Seattle figures indicate that equipment, maintenance and repairs, depreciation, and so forth comprise 47 percent of sweeping costs while labor comprises the remaining 53 percent. Converting these percentages to cost per square meter gives $0.0008 for equipment (non-labor inputs) and $0.0008 for labor.

The City of Portland Bureau of Maintenance operates three mobile flushers, each a part of a street cleaning crew. Because the operations of flushing and sweeping are combined and because other operations such as traffic control are also included, the separate costs of street flushing are difficult to infer.

Total curb mileage for all three crews for the 1981-82 fiscal year was 28,097 miles. Dividing by 3, since there are 3 crews, gives 9,366 miles per flusher per year. The cost per flusher per year was given as $140,000, but it was impossible to confirm this figure in subsequent conversations. Further, it is not clear if this was the cost for the flusher alone, or for flusher, labor, and so forth. The assumption made here is that $140,000 represents all costs for flusher, labor, etc. to cover 9366 miles in one year.

The following calculates the cost per square meter and adjusts for seven hours production in an eight-hour shift:

$$\frac{\$140{,}000 \text{ per year}}{9366 \text{ mi/yr} \times 5280 \text{ ft/mi} \times 20 \text{ ft wide} \times 0.093 \text{ m}^2\text{/ft} \times 7/8} = \$0.0017/\text{m}^2$$

The average hourly rate of a flusher is easier to calculate. The total 28,097 curb miles for one year took a total of 819 shifts. This works out to an average of 34.3 miles per shift. The adjusted average hourly rate is:

$$34.3 \text{ mi/shift} \times 5280 \text{ ft/mi} \times 20 \text{ ft wide} \times 0.093 \text{ m}^2\text{/ft}^2$$

$$\times\ 7/8 \text{ productive hrs/shift} \times 1/8 = 36{,}843 \text{ m}^2\text{/hr}$$

The Portland data also included some useful figures regarding the costs for the different inputs. They have three street maintenance crews consisting of five people in each. Each crew consists of the items shown in Table A.1.2.3.

TABLE A.1.2.3. Typical Street Maintenance Crew, City of Portland

Labor	Capital
2 sweeper drivers	2 mobile sweepers
1 flusher driver	1 mobile flusher
1 utility worker	1 pickup truck
1 laborer	-----

They provided costs by input for the combined operations of all three crews. They also provided the cost by input for some of the flushing operations alone. More specifically, these are the costs of flushing the core (business) area and arterials. Excluded are the costs of flushing residential areas.

TABLE A.1.2.4. Portland Street Flushing Cost Data

Input	Cost of All Operations: 1982 Dollars	Cost of All Operations: Percent	Cost of Flushing Limited Area: 1982 Dollars	Cost of Flushing Limited Area: Percent
Labor	457,000	55	108,000	55
Materials	13,000	2	4,000	2
Fleet	364,000	44	82,000	42
Unspecified	2,000	0	1,000	1
Total	836,000	100[a]	195,000	100

(a) Parts do not add to total due to rounding.

While the mileage corresponding to the limited flushing figures was not available, the data were useful in showing that the cost shares of the various inputs are fairly constant, so that even with incomplete information on flushing we can be reasonably confident that the proportions calculated for the limited area are likely to be very close to the proportions of total sweeping costs. Applying these proportions to the estimated cost per square meter, we can estimate the input costs per square meter, as shown in Table A.1.2.5.

The September, 1982 version of PIN's (Product Information Network) report on street sweepers includes information on the cost of mobile street flushing. They report (p. 17) that the annual cost of flushing is $150 per

TABLE A.1.2.5. Street Flushing Input Costs, City of Portland

Input	Percent of Total	Cost ($/m^2)
Labor	55	0.0009
Materials	2	0.0000
Fleet	42	0.0007
Unspecified	1	0.0000
TOTAL	100	0.0017

curb mile per year with one flush every five days. Interpreting this to mean one pass per week or 50 passes per year, the cost per curb mile per pass is $3.00. Note that this figure is substantially less than any other reported.

The cost per square meter (adjusted for production in only seven of eight shift hours) was calculated as follows:

$$\frac{\$3/\text{mi}}{(5280\ \text{ft/mi} \times 20\ \text{ft wide} \times 0.093\ \text{m}^2/\text{ft}^2)} \times \frac{8}{7}\ \text{adj} = \$0.0003$$

The document indicated that the flusher operated at the same speed as a street sweeper (about 8593 square meters per hour). This is problematical for two reasons. The first is that the other sources providing flushing data indicated that flushers normally operate at about twice the forward speed of street sweepers. The second reason to suspect a faster forward speed is that procedures such as these, which are capital- and labor-intensive rather than materials-intensive, will tend to have lower costs at faster rates. Since the cost given here is quite low, one would expect a corresponding faster than average speed. The result of these considerations is to conclude that the information in PIN does not provide a sound basis for estimating production rates. The information in PIN also provides no basis for calculating the shares of total costs by input.

The Maintenance and Operations Division of the State of Washington Department of Transportation estimates its cost of street flushing at $11.71 per lane mile. Its performance standard for flushing is 1.667 lane miles per hour, a much lower rate than reported by other sources. The area flushed in one hour, adjusted for time for radiation control, is:

$$1.667\ \text{mi/hr} \times 5280\ \text{ft/mi} \times 20\ \text{ft wide} \times 0.093\ \text{m}^2/\text{ft}^2 \times 7/8$$
$$= 14{,}325\ \text{m}^2/\text{hr}$$

At 1.667 miles per hour, Washington's cost per hour is:

$$1.667\ \text{mi/hr} \times \$11.71/\text{mi} = \$19.52/\text{hr}$$

Dividing the cost per hour by the average hourly production yields the cost per square meter:

$$\frac{\$19.52}{14{,}325} = \$0.0014/\text{m}^2$$

According to this source, the cost of street flushing can be broken down as shown in Table A.1.2.6. Input costs per square meter are estimated by applying the same input cost shares already reported to the (adjusted) cost per square meter.

The Radiological Reclamation Performance Summary, Vol.II (Owen et al. 1967) reports detailed performance data regarding mobile street flushers but provides no information about costs. The performance figures in Owen et al. are somewhat at variance with those supplied by other sources. The major difference is that the tests and subsequent calculations for coverage rate and

TABLE A.1.2.6. Washington State Department of Transportation Estimates of Street Flushing Costs by Input

Input	Reported Cost (1982 \$/mi)	Reported Percent[a]	Adjusted Cost (1982 \$/m^2)
Labor	6.06	52	0.0007
Equipment	5.11	44	0.0006
Materials	0.54	5	0.0001
TOTAL	11.71	100	0.0014

(a) Parts do not add to total due to rounding.

removal efficiencies reported by Owen et al. were based on an average effective flushing width of about 5.2 feet rather than the 20 feet reported by other sources. Vehicle speed was 6 miles per hour. As mentioned earlier, the usual practice for flushing streets is for the mobile flusher to direct a spray of water from the center of the street toward the curb. In this manner, either one or both halves of an average 40-foot wide urban street can be flushed in one pass. The apparent assumption in the Radiological Reclamation Performance Summary was that greater water pressure and, hence, greater scouring action of a direct water spray was necessary to produce sufficient removal. Other available sources concerned with mobile street flushing as a method of radiation decontamination provide no details about the flushing procedure.

This low flushing width was partially offset by an average effective operating speed of 6 miles per hour, which is faster than that reported by most other sources. Even so, the reported coverage rate of 15,345 square meters per hour in Owen et al. is still comparatively low. Adjusting for an hour per shift due to radiation control measures, we get:

$$15{,}345 \text{ m}^2/\text{hr} \times 7/8 = 13{,}427 \text{ m}^2/\text{hr}$$

The previously reported flushing data from other sources resulted in low unit costs in large part because of the high rate of coverage. If a 20-foot flushing width per pass is unrealistic, then the previously reported costs could be converted to a 5-foot width basis by multiplying all cost figures by 4 (20 ft ÷ 5 ft = 4). This adjustment seems more appropriate than the alternative one of increasing unit costs by the ratio of the estimated coverage rates:

$$\frac{\text{est. coverage rate for source A}}{\text{est. coverage rate for Owen et al.}} \times \text{est. unit cost for source A}$$

$$= \text{adjusted unit cost for source A}$$

This adjustment, which converts all costs to an hourly coverage rate of 13,427 square meters, suppresses the collected information on vehicle speed. In addition to assuming an effective flushing width of about five feet, it also assumes an average speed of 6 miles per hour.

An important reason for not adjusting all costs and rates to a narrower width basis is that a narrow width, direct water spray method is analyzed in the next section. Those cost and rate estimates can be used if 20-foot wide flushing proves unsatisfactory.

A final detail reported by Owen et al. is that the flusher discharged water at the rate of 370 gallons per minute, for a coverage of 0.13 gallon per square foot. Also, nearly half of the operating time was spent in refilling the flusher.

Table A.1.2.7 summarizes the foregoing mobile street flushing data. While most of the figures are fairly consistent, the PIN data show an exceptionally low rate and low unit cost, and the rate reported by Owen et al. is slightly below that for the Washington Department of Transportation. All rates were

TABLE A.1.2.7. Summary of Mobile Street Flushing Data

Source	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Non-Labor
Los Angeles Pub. Works	42,996	0.0011	---	---
San Francisco Pub. Works	42,996	0.0009	0.0006	0.0003
Seattle Pub. Works	26,854	0.0016	0.0008	0.0008
Portland Bur. of Maint.	36,843	0.0017	0.0009	0.0008
PIN	8,593	0.0003	---	---
Washington Dept. of Trans.	14,325	0.0014	0.0007	0.0007
Owen et al.	13,427	---	---	---
Representative	26,576	0.0013	0.0007	0.0006

averaged to produce the representative rate. The PIN unit cost was omitted in computing this cost.

Of the sources that provided data for allocating input costs, all designated labor as one of the categories. Beyond that, however, the categories varied. Potential inconsistencies were resolved by lumping all non-labor costs together. The representative input unit costs were calculated in two different ways, but which produced the same result. In the first method, the four input costs were averaged and then proportionally adjusted to the representative total cost. The other method was to convert each source's input cost to a percentage of total unit cost and then to average these percentages. Then the average input cost shares were applied to the $0.0013 per square meter unit cost to give the input costs.

A.1.3 High Pressure Water

Using a high pressure water wash of 80 to 120 pounds per square inch has the advantage of scouring the pavement. This will result in greater removal of small particles and particles which have penetrated into surface irregularities. There are three basic methods for carrying out this procedure. The first method requires a high pressure fire hydrant system. Crews of two or three workers equipped with a small amount of equipment, primarily fire hoses and nozzles, move from hydrant to hydrant hosing down the pavement by section.

The second method would be used principally in cases where there were no hydrants or where the hydrant system provided inadequate pressure. In this method, water from a hydrant or from a water tanker truck would be supplied to a pump truck which would boost the pressure and supply it to one or two hose lines.

The third method is to use a tank truck fitted with a pump and a set of spray nozzles mounted on a boom across the front of the truck. This equipment would have the capability of applying the water over the width of a lane and would be able to move forward while spraying.

Each of the three methods is discussed in detail below, and cost estimates are given for each. These estimates are weaker than some others in this study due to the fact that high pressure washing of pavement is not an activity which is commonly performed. Therefore, cost estimates were constructed from information on the factor inputs and their likely costs; the estimates are generally not based on experience.

The method using the least amount of specialized equipment requires equipping two- or three-man crews with about 500 feet of firehose (in 50-foot sections with coupling fixtures), a nozzle, a hydrant wrench, and a limited amount of miscellaneous personal equipment, such as rubber boots and other waterproof and protective clothing. The hoses would be connected to a hydrant and used to spray the pavement. Two people may be required to hold the hose if higher pressures are used. After spraying the pavement, workers would drag the hoses to the next hydrant and repeat this operation.

It is interesting that some data from a similar operation was recorded from actual experience in the cleanup of volcanic ash following the eruption of Mount St. Helens in 1980. That event created a situation not entirely unlike the one which would result from a nuclear reactor accident. While the ash did not create a radiation hazard, the sheer volume of material made a large-scale cleanup program necessary. Of course, removing a large volume of ash is not the same as removing an essentially invisible coating of radioactive fallout.

However, in some cases the costs and methods of the two may be similar. For example, in the absense of better data, the cost and rate for hosing a thick coating of volcanic ash from paved surfaces might be a good proxy for the cost of hosing paved surfaces to remove a thin but tenacious coating of radioactive particles. Both operations require a degree of thoroughness - one in order to remove a high volume of material and the other to remove particles with great adhesion to the surface.

The Administrative Services Manager of Spokane Community College directed the cleanup of that campus. Of the total 200 acres, 110 acres were paved. He reported that, on average, one man could hose down a length of street a block long in one hour. Including sidewalks, he estimates the area covered in an hour at 15,000 square feet. This estimate was the result of actually timing the operation. In addition, 15 minutes were required to move the hose from one hydrant to the next. This brings the effective rate down to 15,000 square feet every 75 minutes. If one hour per shift is devoted to equipment and personnel decontamination activities, the coverage rate is:

$$15{,}000 \text{ ft}^2 \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ prod. hrs/shift} \div 1.25 \text{ hrs}$$
$$= 977 \text{ m}^2/\text{hr}$$

The average straight-time salary at the time of the eruption was $6.00 per hour. Here we use a burdened labor cost figure of $17.45 per hour. In addition to these costs were the costs for equipment. This same source reported that the hose and most fittings had to be replaced after two weeks of round-the-clock use. (Sources in the Seattle Fire Department indicated that they would expect a shorter life than two weeks if the hoses were regularly dragged across pavement.)

Apparently, various hose setups were tried. The one for which they reported the greatest success was a Y-setup with one 2-1/2-inch connection to a hydrant. The 2-1/2-inch hose, in (usually) six 50-foot sections led to a Y-valve to which two lines of 1-1/2-inch hose were connected. The 1-1/2-inch lines were usually comprised of 50-foot sections. Each 1-1/2-inch line was separately manned. There was a nozzle at the end of each 1-1/2-inch line, of course. This source reported the cost of 1-1/2-inch hose at $1.30 per foot and the cost of 2-1/2-inch hose at $1.70 per foot. These costs include couplings and their attachment to the hose. Without including the Y-valve or the nozzles, the cost for this apparatus comes to $900.

The general magnitude of these prices was confirmed by a company which specializes in fire hose equipment, Sherman Supply and Salvage Co. in Seattle. Its price information is presented in Table A.1.3.1. A standard length of hose is 50 feet and prices include couplings. Double jacket hose will handle higher pressures than single jacket and will wear longer when the hose is being dragged.

Periodic replacement of the worn-out hose would cost somewhat less than the amounts given because the fittings could be reused. On the other hand,

TABLE A.1.3.1. Calculation of Hosing Equipment Costs

Item	Quantity	1982 $ Price	Cost
2-1/2 inch hose, 50 foot length, double jacket	6	$75	$450
1-1/2 inch hose, 50 foot length, double jacket	6	$55	$330
Y fitting 2-1/2" - 2x1-1/2" with valves	1	$86.59	$ 86.59
Industrial fog nozzle, with valve	2	$22.50	$ 45.00
Total			$911.59

Source: Sherman Supply & Salvage Co., Seattle, Washington.

the Seattle Fire Department was skeptical whether a fire hose would last even as short a period as two weeks with constant dragging over pavement. For this work we used a figure corresponding to $1000 for every 2 weeks of continual use. The additional cost was to account for incidental equipment expenditures such as personnel water protection clothing. The equipment cost per hour, then, is:

$$\frac{\$1000}{2 \text{ wks} \times 7 \text{ days} \times 24 \text{ hrs}} = \$2.98/\text{shift-hour}$$

Adding this to the cost of labor brings the total cost per hour to $20.43. Dividing this by the average hourly production gives a cost per square meter of $0.021.

Owen et al. reported detailed performance information for firehosing, but no cost data. The most important of these results for the purposes at hand concerns removal of particles in the 44-to-88 micron size range from roughly textured asphalt or concrete using a 1.5-inch fire nozzle with a 5/8-inch bore. Nozzle pressure was 75 pounds per square inch, and the initial contaminated mass loading was 5 grams per square foot. Under these conditions, the amount of water used was 0.22 gallon per square foot, which is equivalent to a 0.35-inch coverage of water. The reported "working rate" was 450 square feet per hour, but the effective rate--taking into account support services and 20 minutes to disconnect from one hydrant, move, and reconnect to the next--was 270 square feet per minute. This works out to 16,216 square feet per hour, which is in reasonable agreement with the unadjusted rate reported from Spokane Community College. This figure, therefore, includes the 20 minutes.

Owen et al. suggested additional adjustments to compensate for fatigue. Coverage rates should be reduced by 20 percent where: a) 4-hour shifts are planned for persons obviously not conditioned to physical labor, or b) 8-hour shifts are planned for experienced and properly conditioned crews. No adjustment was recommended for well-trained and conditioned personnel working 4-hour shifts. Since calculations in this document are based on 8-hour shifts, the coverage rate needs to be adjusted. Further adjustment is necessary for one hour per 8-hour shift lost to exigencies of the hazardous conditions. With these adjustments and conversion to metric units, we get:

$$16,216 \ ft^2/hr \times 0.80 \text{ fatigue adj.} \times 7/8 \text{ adj.} \times 0.093 \ m^2/ft^2$$
$$= 1056 \ m^2/hr$$

This figure is quite close to the adjusted rate calculated for Spokane Community College. The average of the two rates is 1017 square meters per hour.

Table A.1.3.2 summarizes the rate and cost information for manual firehosing. Labor comprises 85 percent and equipment 15 percent of the operation.

Estimating the cost of high-pressure hosing of pavement using fire equipment such as pumpers and tankers is difficult because fire fighting

TABLE A.1.3.2. Summary of Manual Firehosing Information

Source	Water Applied (in.)	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment
Spokane Com. Coll.	0.64	977	0.021	0.018	0.003
Owen et al.	0.35	1056	---	---	---

equipment is used for emergencies, not continuous operation. Moreover, the personnel which use the equipment are specially trained for emergency operations. This sort of usage is much different from the relatively slow, methodical, and repetitive operation of hosing down streets as might be done following a nuclear reactor accident. The major differences as they would bear on costs are apparent. Equipment and personnel would be in near-continual use. This would have the effect of lowering the average cost per hour of operation of both labor and equipment. Further, it would not be necessary to employ such highly trained and highly paid people as firefighters. For these reasons, the information provided by fire department sources occasionally needs to be adjusted by a significant amount.

Pump trucks commonly have the ability to pump 100 gallons per minute at 100 pounds per square inch. However, the equipment can be adjusted to put out less water at higher pressures or more water at lower pressures. Pump trucks themselves generally have a 500-gallon tank capacity. At a pump rate of 100 gallons per minute, it is clear that pumpers require some additional water supply. The two alternatives for this are i) attachment to a hydrant or ii) use of a shuttle of tanker trucks. Tanker trucks normally have a capacity of 2,000 to 3,000 gallons. Larger capacity water transport vehicles do exist. A pumping rate of 100 gallons per minute would require a tanker-load of water, say, every 30 minutes of pumping. The number of tankers required to keep a pumper supplied will depend on the travel time to and from the water source, the time to refill a tanker, and the length of any interruptions in pumping by the pumper. Here we assume that three tankers per pumper are sufficient.

With respect to the labor requirements for high-pressure hosing of streets, sources associated with fire departments, not surprisingly, responded in terms of standard firefighting crews. Thus, both the Richland, Washington, Fire Chief and the Director of Finance of the Seattle Fire Department indicated that the crew for each pumper should consist of two firefighters and one officer and for each tanker there should be one firefighter. The Chairman of the International Fire Chiefs Association Hazardous Materials Committee recommended four people per pumper and three people per tanker.

Here we assume that with fire hydrants three people with one pumper will be sufficient. The Richland Fire Chief provided labor and equipment costs that have been standardized across Washington State. This standardization was done by the State Fire Chiefs Association for the purpose of interdepartmental billing when one department loans some of its equipment and personnel to a neighboring department for firefighting. At these rates a firefighter costs $15 per hour, an officer $20 per hour, a pumper $85 per hour plus $1.50 per mile, and a 1250-gallon tanker $35 per hour plus $1 per mile. The Seattle Fire Department provided similar labor costs--$15 per hour for a firefighter and $18 per hour for an officer. Both sets of labor costs include salaries and benefits.

The lesser of these two sets of labor cost figures comes to $48 per hour for a three-man crew. As mentioned earlier, for decontimination work it would not be necessary for all workers to have the training, skills, and experience of firefighters. However, some specialized skill would be required for operation of the pumper. For the purposes at hand, we use $48 per hour for the three-man crew. The $85 charged per hour of use for the pumper may overestimate the average hourly cost with continuous operation. Nonetheless, that figure was used here since there was no basis for doing otherwise. Therefore, with hydrants available to supply water to the pumper, the total cost per hour is $133. Labor accounts for 36 percent of the total, and the remaining 64 percent goes for capital, as well as operation and maintenance.

The estimates for the time required to adequately hose a paved surface varied greatly. The Chairman of the International Fire Chiefs Hazardous

Materials Committee indicated that adequate hosing would require 500 gallons for 100 square feet. This is a huge amount of water. It is equivalent to covering all paved surfaces with water to a depth of eight inches. If we assume 16 blocks per mile with streets 40 feet wide, there are 13,200 square feet of street pavement per (linear) block. At a pumping rate of 100 gallons per minute, this coverage would require 11 hours per block.

In contrast, Nowell Patten, of the International Association of Fire Chiefs, estimated 15 to 20 minutes per block, excluding setup time. Close to this estimate was the one from the Seattle Fire Department Research and Development Section. They estimated half an hour for hosing one linear block and ten minutes for moving and setting up for the next block. The Richland, Washington Fire Department source felt that one to two hours per block would be required.

Of course, the length of time for hosing will be at least partially a function of the desired thoroughness, or level of decontamination, to be achieved. Unfortunately, except for Owen et al., the available references for the effectiveness of high-pressure hosing are not clear about the amount of water per surface area used. The coverages reported in Owen et al. range from 0.21 inches to 0.51 inches per pass. In fact, establishing a fixed water coverage per pass is arbitrary since one pass of, say, 1.00 inch of water should have about the same effectiveness as two passes of 0.50 inch of water. Lacking a more definitive standard, the coverage rate used here has been set equal to 0.50 inch. One reason for choosing this relatively heavy coverage is that because moving and setting up at a new location are costly, it is more economical to apply more water in fewer passes than less water in more passes.

Referring to Table 3.1 in Owen et al., we find that a coverage of 0.50 inch (0.31 gallon per square foot) can be applied at an effective rate of 213 square feet per minute. This allows 20 minutes for reconnecting to the next fire hydrant. This rate is equivalent to 1189 square meters per hour. With the final adjustment of one hour per shift for radiation protection measures and reduced productivity, we get 1040 square meters per hour.

The cost per square meter is:

$$\frac{\$133/\text{hr}}{1040\ \text{m}^2/\text{hr}} = \$0.13/\text{m}^2$$

In the event that fire hydrants are not available, it would be necessary to add the cost of three tanker trucks and their drivers. We assume a cost of \$17.45 per hour for the drivers. Recalling that the rental rate for a 1250-gallon fire department tanker in Washington is \$35 per hour plus \$1 per mile, we assume an average hourly cost of \$50 per hour per tanker. This accounts for a larger tank capacity and about 10 miles driving each hour. With three tankers and three drivers, the cost of supplying one pumper with water is \$202.35 per hour. The additional cost per square meter is:

$$\frac{\$202.35/\text{hr}}{1040\ \text{m}^2/\text{hr}} = \$0.19/\text{m}^2$$

This brings the total cost per square meter to $0.32. The share of the total cost comprised by labor is 26 percent, and that comprised by capital and operation and maintenance is 74 percent.

Standard fire department pump trucks are designed for stationary use. They are generally positioned at a convenient location for firefighting and kept there until the truck is no longer needed for that fire. In contrast, hosing pavement requires forward movement, even if the movement is slow. For this reason, other sorts of equipment were investigated.

Both the Forest Service and airport firefighting units have what is referred to as "pump and roll" equipment--equipment designed to pump water from a nozzle while the vehicle is moving. Unfortunately, for the purposes at hand, this equipment generally has a much too limited tank capacity, often less than 100 gallons.

When posed the question of how to efficiently accomplish a high-pressure hosing of very large areas of pavement, four different sources suggested essentially the same approach. These sources included contacts at the Portland, Oregon, and Wenatchee, Washington, offices of the U.S. Forest Service, at the U.S. Bureau of Land Management Interagency Fire Center in Boise, Idaho, and at Wajax Firefighting Equipment, Seattle, Washington. The method they suggested was to fit a 3,000-gallon tank truck with a pump and a multi-orifice spray-bar. None of the sources indicated that there would be any problem in assembling such a rig. Further, the same basic equipment with some variation in pump size and the spray-bar could be used for low-pressure flushing, high-pressure flushing, very high-pressure flushing, and other applications of liquids to roads. The major difference in equipment for these functions is pump size.

While a 20-horsepower pump can generate a flow rate of 100 gallons per minute at 100 pounds per square inch, the flow rate drops sharply if the same pump is set for 400 pounds per square inch. The result is that a substantially larger pump is required to generate both pressure and volume.

Besides the fact that the same basic equipment configuration can be used for low-, high-, and very high-pressure flushing, equipment of this sort may be immediately available. According to the Forest Service in Portland, heavy construction contractors use and rent this equipment. The Interagency Fire Center said that the military has a large surplus quantity of high-pressure, high-volume trucks for sale.

According to Wajax Firefighting Equipment, a new 3,000-gallon tank truck would cost about $25,000 and the auxiliary equipment would add another $6,000-$8,000 to the cost, bringing the total to something like $32,000. The source added that the General Services Administration estimates the charges for a 1,000-gallon truck-sprayer at $19.60 per hour for operation and maintenance plus $500 per month for charges against capital. On this basis Wajax estimated the comparable charges at $25.00 per hour and $600 per month for a 3,000-gallon rig. At a spray rate of 100 gallons per minute, the truck can spray for 30 minutes before refilling. Refilling time depends on the method. A gravity feed from an elevated tank would take only two to four minutes. A hydrant with a four-inch fitting could fill the tank in 10 minutes, while refilling from a pool with a booster pump would take 20 minutes. In addition, there would be travel time to and from the fill site. Assuming 20 minutes for filling and traveling plus one hour per shift for equipment and personnel radiation decontamination, there are 4.2 hours for spraying. This gives 8.4 loads of 3,000 gallons each applied per shift, ignoring the problem of fractional tanker loads (shift length could be adjusted).

Assuming 43 shifts per month and 8 hours per shift, the hourly charge was figured as the sum of the monthly rental rate plus the hourly operation and maintenance charge plus the operator's salary:

$$\frac{\$600/\text{mo}}{43 \text{ shifts} \times 8 \text{ hrs/shift}} + \$25/\text{hr} + \$17.45/\text{hr} = \$1.74 + \$25 + \$17.45$$

$$= \$44.19/\text{hr}$$

Using these cost figures, labor comprises about 39 percent, capital 4 percent, and operation and maintenance 57 percent.

Given the spray rate of 100 gallons per minute over a ten-foot width, the truck's speed is inversely related to the amount of water applied to the pavement. For an average of half an inch of water, the truck's speed would be 0.36 miles per hour. For twice as much water, an inch, the speed would be half that--0.18 miles per hour. On the other hand, looking at the coverage as determined by the speed, a speed of one mile per hour gives a coverage of 0.18 inches of water. Using this one mile per hour speed, the total coverage per shift would be:

$$1 \text{ mi/hr} \times 4.2 \text{ spraying hrs} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$= 20{,}624 \text{ m}^2/\text{shift}$$

The average coverage per shift hour is, therefore, 2,578 square meters. Dividing this into the cost per hour yields a cost per square meter of $0.017.

The Bureau of Land Management Interagency Fire Center provided information on a 9,000-gallon capacity tractor-trailer rig. The cost of this equipment is shown in Table A.1.3.3. These figures are considerably higher than those supplied by Wajax for two reasons. The tank capacity is triple that represented by the Wajax data. Also, the pump in the BLM equipment is much larger. Note that the pump is mounted on a separate trailer. While it could be mounted on the truck frame itself, the BLM source said that this arrangement would facilitate using the truck's own pump to fill the tank if filling were to be done from a pond.

The price of the pump varies with the model selected. This source provided the following prices for various Hale brand pumps. The flow rates shown in Table A.1.3.4 are all given at 150 pounds per square inch pressure.

TABLE A.1.3.3. Firehosing Equipment Costs, Bureau of Land Management Interagency Fire Center

Item	Price
Tractor	70,000
Trailer (9,000 gal Brauhaus)	30,000
Spreader bar, installed	5,000
Pump	11,550-13,800
Add'l trailer for pump	4,340
Total	$120,890-123,140

TABLE A.1.3.4. Flow Rates and Prices for Hale Pumps

Hale Pump Model	Rate (gal/min)	Price (1982 $)
FB50-F300	700	$11,550
FB50-C318	850	12,475
FB75-C318	850	12,750
FB75-F460	750	13,500
FB100-F460	1100	13,800

The price differences are due to valves and other fittings as well as flow rates. A precise evaluation of the proper choice of pump would involve weighing the values of the marginal products of the various inputs. Lacking the ability to do that, it can be noted that the last and most expensive pump on the list gives the highest pump rate per dollar. Also, the marginal cost for additional pump capacity generally declines for these models as capacity increases. As a result, further calculations will be made based on the largest of the pumps shown on this list.

The source gave the hourly operation and maintenance cost at $20 per hour. This figure is not consistent with the higher figure for the smaller rig described by Wajax. It seems more likely that the BLM figure is too low rather than the Wajax figure too high. Arbitrarily, we assume an hourly operation and maintenance charge of $35. The monthly capital equipment charge will be more or less proportional to the total purchase price. Using the Wajax figures to estimate the monthly equipment charge on this basis, we get $2300.

As in the previous case, the cost per hour comes from summing the average capital cost, the operation and maintenance cost, and the operator's salary:

$$\frac{\$2{,}300/\text{mo}}{43 \text{ shifts} \times 8 \text{ hrs/shift}} + \$35/\text{hr} + \$17.45/\text{hr} = \$6.69 + \$35 + \$17.45 = \$59.14$$

Of this amount, labor comprises 30 percent, capital 11 percent, and maintenance and operation make up the remaining 59 percent.

At a pump rate of 1,100 gallons per minute, the entire 9,000-gallon tank capacity will be expelled in a little over 8 minutes. This would permit the truck to drive faster while spraying. Here we assume 30 minutes total time for refilling, including travel to and from the fill site. This assumes a faster fill rate than for the 3,000-gallon truck, which would be likely if this larger-size equipment were used and higher-capacity pumps were purchased. Over a seven-hour period this equipment should average about 11 tank loads applied, with about 1.5 hours actual spraying time.

Again, the vehicle's speed and the amount of water sprayed per unit area are inversely related. Since the pump rate is 11 times that of the 100 gallon per minute equipment, the same coverage can be attained at a vehicle speed 11 times faster. Thus, for a coverage of half an inch, vehicle speed would be four miles per hour. This equipment would get the same coverage (0.18 inches) at 11 miles per hour that the 100 gallon per minute pump would produce at one mile per hour.

Assuming a vehicle speed of ten miles per hour (coverage of 0.20 inches), the area covered per shift would be:

$$10 \text{ mi/hr} \times 1.5 \text{ hrs spraying} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$= 73{,}656 \text{ m}^2$$

The average coverage per shift hour would be one-eighth of this amount, or 9,207 square meters. The cost per square meter works out to:

$$\frac{\$59.14/\text{hr}}{9207 \text{ m}^2/\text{hr}} = \$0.006/\text{m}^2$$

The Portland office of the U.S. Forest Service advised that a 3,000-gallon capacity tank truck with pump and spray bar would cost about $68,000 new. The performance specifications for this equipment were essentially the same as those described by Wajax Firefighting equipment. The only difference is the higher capital cost. This source was not able to provide additional cost data. Since there was no other new information from this source, apart from the purchase price, the same calculations as were done with the Wajax data were repeated. Only the capital cost figure was changed.

The monthly capital equipment cost was adjusted proportionately to the higher purchase price. This raised the hourly charge for capital to $3.71. Proceeding with exactly the same calculations as for the Wajax data, we get a total hourly cost of $46.16, of which labor comprises 38 percent, capital 8 percent, and operation and maintenance 54 percent. The cost per square meter is $0.018 at the same rate of 2578 square meters per hour.

Means' Building Construction Cost Data 1982 provided information that can give an indication of the cost of the operation. The lease and operating costs of a truck tractor and water tank trailer with engine-driven discharge are listed. A detailed description of this equipment is not available, so it is assumed that even if this equipment is not suitable for high-pressure pavement washing, the costs are not greatly different from the costs of proper equipment.

Four types of truck tractors are listed, differing in load capacity. The choice of tractor is therefore determined by the choice of trailer. Here there are two choices, one with a 5,000-gallon capacity and the other with a 10,000-gallon capacity. The truck tractors that appear to be appropriate for these trailers are, respectively, one with 195 horsepower and a 30-ton capacity, and one with 240 horsepower and a 45-ton capacity. The costs of these two rigs, as printed in Means, are shown in Table A.1.3.5.

TABLE A.1.3.5. Means Cost Data for Firehosing Equipment

	Hourly Oper. Cost	Rent per Month
30-ton tractor	\$ 8.10	\$1675
5,000-gallon trailer	8.40	1975
Total	\$16.50	\$3650
45-ton tractor	\$12.25	\$2400
10,000-gallon trailer	9.95	2875
Total	\$22.20	\$5275

With two shifts per day, there are 336 hours per month. Dividing by this number gives an hourly rental cost for the smaller equipment set-up of \$10.86 and \$15.70 for the larger one. Total hourly equipment cost is, then, \$27.36 for the 5,000-gallon arrangement and \$37.90 for the 10,000-gallon arrangement. Added to each of these is the \$19.75 hourly labor cost for a heavy-truck driver.

The coverage rates for these two truck-trailer rigs are estimated in a manner similar to the previous estimates. At an assumed discharge rate of 100 gallons per minute, the 5,000-gallon tank would provide water for 50 minutes. If refilling takes 30 minutes and there are seven hours per eight-hour shift available for spraying, then 5.25 tank loads per shift could be applied. With 50 minutes spraying time per load, the total spraying time would be 4.375 hours per shift. Total surface coverage would be

$$1 \text{ mi/hr} \times 4.375 \text{ hrs. spraying/shift} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide}$$
$$\times 0.093 \text{ m}^2/\text{ft}^2 = 21{,}483 \text{ m}^2/\text{shift}$$

Hourly coverage would be one-eighth of this amount, or 2685 square meters.

For the 10,000-gallon truck-trailer setup, one tankload would provide 100 minutes of spraying at the 100 gallons per minute rate. If refilling takes 40 minutes, then a complete cycle of refilling and spraying will take two hours and 20 minutes. With seven production hours per shift, three tank loads will be sprayed, giving a total spraying time of five hours. Coverage in one shift will be

$$1 \text{ mi/hr} \times 5 \text{ hrs} \times 5280 \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 = 24{,}552 \text{ m}^2$$

One-eighth of this amount, 3069 square meters, is the average hourly coverage.

Having the coverage rate, it is easy to calculate the cost per square meter. They are as shown in Table A.1.3.6.

TABLE A.1.3.6. Summary of Means Cost Data

Tank Capacity	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment
5,000 gallon	2685	0.0176	0.0074	0.0102
10,000 gallon	3069	0.0187	0.0064	0.0123

Table A.1.3.7 summarizes the foregoing information regarding the high-pressure hosing of pavement. One thing that is apparent is that the cost estimates cover a wide range. The highest cost estimates were those using fire department data. Using fire department pump trucks tends to be a slow method which also requires more equipment and more personnel per unit area. Of the methods presented, clearly the simplest one is to supply workers with hoses and little else. This method is quite practicable from a cost standpoint, too, as long as hydrants or high-pressure water mains are accessible. The BLM cost figure is significantly lower than all others. This low cost is primarily the consequence of utilizing a high output pump. Since Wajax, the Portland Forest Service office, and the Wenatchee Forest Service office all specified the same equipment and only the Bureau of Land Management Interagency Fire Center specified this high-volume equipment, there is a question as to whether the high-volume equipment is as common and as readily available. If this equipment is readily available, then it would be the preferred choice. If hydrants are available and the application of a high-volume of water is deemed desirable, then manual hosing would probably be the choice. In cases where neither high-pressure hydrants nor the BLM-specified equipment is readily available, as may be likely, the Wajax-Forest Service figures become the preferred choice. All non-labor costs are included under the equipment heading.

A representative cost would appear to be about \$0.018. Rates and cost shares are more widely dispersed. In general, the Wajax and the Means figures for the 5,000-gallon equipment seem fairly reliable and not extreme; they were taken as representative.

A.1.4 Very High-Pressure Water Flushing

The porosity of asphalt and concrete will result in some radioactive particles being inaccessible to methods which otherwise have good removal

TABLE A.1.3.7. Summary of High-Pressure Water Cost Data

Method and Source	Vehicle Speed (mi/hr)	Amnt. Water Applied (in.)	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment
Manual firehosing						
Spokane Comm. Col.	--	0.64	977	0.021	0.018	0.003
Owen et al.	--	0.35	1056	--	--	--
Pumper w/ hydrant						
Var. fire depts.	--	0.50	1040	0.13	0.05	0.08
Pumper w/ tankers						
Var. fire depts.	--	0.50	1040	0.32	0.08	0.24
Tanker w/ pump						
Wajax	1	0.18	2578	0.017	0.007	0.010
BLM	10	0.20	9207	0.006	0.002	0.004
Forest Service	1	0.18	2578	0.018	0.007	0.011
Means - 5,000 gal.	1	0.18	2685	0.018	0.007	0.011
Means - 10,000 gal.	1	0.18	3069	0.018	0.006	0.012
Representative	1	0.18	2685	0.018	0.007	0.011

efficiencies. One way to dislodge and remove particles which have become embedded in the pavement surface or have penetrated into crevices below the surface is to use a very high-pressure water wash. At pressures around 400 pounds per square inch there is a good scouring action. However, in some cases water at this pressure may actually erode and break up some asphalt pavements.

According to Wajax Firefighting Equipment in Seattle, Washington, the most efficient way to accomplish a very high-pressure water scouring of pavement seems to be to use an equipment arrangement similar to that described previously in the discussion about high-pressure (100 pounds per square inch) water flushing. A tank truck with a capacity of, say, 3,000 gallons is fitted with a pump and a spray bar. With this setup, the truck can spray a ten-foot wide swath of pavement as it moves forward.

The major difference between the equipment required for the 100 pounds per square inch wash and the equipment required for the 400 pounds per square inch wash is the pump size. In order to maintain a flow rate of 100 gallons per minute at this higher pressure, a large pump driven with a V6 or V8 engine is necessary. Such a pump may be towed behind the truck on its own trailer or mounted on a larger truck frame. A 5-ton truck chassis would be required for the tank, pump, spray bar, and necessary auxiliary equipment.

The pump will cost about \$20,000 and the truck about \$35,000, for a total of \$55,000. Wajax suggested monthly lease payments of \$600 for equipment costing \$32,000. Using a proportional relationship, the monthly capital charge for this equipment is about \$1030. With slightly less than an average of 22 working days per month and two shifts per day, this works out to:

$$\frac{\$1030/\text{mo}}{43 \text{ shifts} \times 8 \text{ hrs/shift}} = \$3.00/\text{hr}$$

Wajax did not provide an hourly operation and maintenance cost for this equipment, but with the larger pump and pump engine we can assume it will cost more to run than equipment detailed in the section about high-pressure water flushing. Here we assume an hourly cost of \$35.00. In addition, there are labor costs of \$19.75 per hour for a heavy-truck driver.

Referring to Means' Building Construction Cost Data 1982, comparable cost figures can be derived. The basic equipment for very high-pressure water scrubbing of pavement would include the 5,000-gallon truck-trailer rig described in the previous section. To this would be added a high-pressure pump. On page 309, Means lists the costs of various diesel and electric firepumps, but it is not clear which, if any, of these would be appropriate. Perhaps the closest match between these pumps and the requirements for pavement washing would be met by modifying either the 85- or 118-horsepower pumps for higher-pressure and lower-volume output. These pumps cost about \$30,000 each. On page 14, a 200-horsepower high-pressure pump is listed along with its hourly operating cost (\$5.60) and the monthly lease rate. The lease rate is given as \$1300 for the first month, \$1180 for the second month, and \$900 for the third month. Assuming that these costs are close to the costs for the proper pump for this application, the cost per square meter can be calculated. We estimate the monthly rental charge for the pump with trailer and other incidental equipment at $1150. This comes to about $3.40 per hour. Adding the operating cost gives $9.00 per hour more for the equipment for very high-pressure (400 pounds per square inch) water spraying compared with the high-pressure (100 pounds per square inch) spraying. This brings the total hourly equipment cost to $36.36.

There is little information about how much water should be used. The Wajax source said that a vehicle speed of from four to six miles per hour should result in good removal. This would result in a surface coverage of about 0.04 inches when the 100 gallons per minute is spread over a width of ten feet. Other sources on decontamination effectiveness were unclear about how much water should be applied to achieve any particular level of effectiveness. The coverage assumed here was 0.18 inches, the coverage resulting from a vehicle speed of one mile per hour. This is at the low end of the amounts of water reported in Owen et al.

With vehicle speed and refilling times about the same as for high-pressure spraying, we can calculate the costs on a square-meter basis by straightforward division. This information is presented in Table A.1.4.1. Note, however, that because water at pressures as high as 400 pounds per square inch may erode and break up asphalt pavement surfaces, it may be necessary for the spray truck to move faster than one mile per hour on asphalt.

TABLE A.1.4.1. Cost Data for Very High-Pressure Water Spraying

Source	Rate (m^2/hr)	Cost Basis	Cost (1982 $) Total	Labor	Equipment
Wajax	2685	$/hr	54.75	19.75	35.00
		$/m^2	0.0204	0.0074	0.0130
Means	2685	$/hr	56.11	19.75	36.36
		$/m^2	0.0209	0.0074	0.0135
Representative	2685	$/hr	55.43	19.75	35.68
		$/m^2	0.0206	0.0074	0.0132

A.1.5 Foam

Acid-based foams rely on maintaining a concentration gradient through the foam's thickness to pull the contamination out of the surface by reverse osmosis. Turco Products, a Division of Purex Corporation, in Carson, California, manufactures chemical bases for such foams. The method they prescribe is to mix the decontamination chemical such as Turco 4512A or Turco 4306D with water. The 4512A comes as a liquid costing $13.00 per gallon and is mixed to a ten-percent solution by volume. The 4306D comes as a powder, sold at $180 for 100 pounds. It is mixed 6 ounces per gallon of water.

The prepared solution is applied by pumping at about 20 to 40 pounds per square inch pressure. The use of a foaming head such as a Dema Model 293 permits mixing with air and Turco 5865 to create a lather-like foam. The Turco 5865 is injected through the detergent supply connection on the foaming head. With the maximum quantity discount, this material costs $6.25 per gallon. It is mixed with the 4512A solution at something like one part foaming agent in ten.

The foam is allowed to remain on the surface for at least an hour and preferably longer. It is then removed with a wet-vacuum and a foam suppressant such as Turco Liquid Lid. This product was not developed as a foam suppressant, but it apparently works better than products that were. A standard mobile vacuumized street sweeper will work for foam pickup. Liquid Lid costs about $10 per gallon.

The prices of the chemicals given here are prices F.O.B. at the Turco plant. Shipping costs will vary according to the distance shipped, of course, and also by the direction shipped, the type of chemical shipped, and the total size of the shipment. Turco estimates shipping charges on the basis of a price scale for different zones. The cost per gallon ranges from $0.60 for shipments going to a zone 1 destination, to $1.20 for shipments destined for locations in zone 6. On the basis of these figures, we assumed an average shipping charge of $1.00 per gallon and $0.10 per pound. This raises the total costs of the chemicals as shown:

TABLE A.1.5.1. Chemical and Shipping Costs for Foam Decontamination

	Costs (1982 $)		
Chemical	Price, F.O.B. Plant	Shipping Cost	Total Price, Shipped
4512A	$ 13.00/gal	$1.00/gal	$ 14.00/gal
4306D	$180.00/cwt	$0.10/lb	$190.00/cwt
5865	$ 6.25/gal	$1.00/gal	$ 7.25/gal
Liquid Lid	$ 10.00/gal	$1.00/gal	$ 11.00/gal

The diluted 4512A solution will cover about 200 to 250 square feet. At $14.00 per gallon, this is equivalent to $0.0753 per square meter using a coverage of 200 square feet per gallon. The 4306D solution has a similar coverage so that the cost per square meter is $0.0363. Since this is less costly than the 4512A, further cost calculations are based on use of 4306D. The foaming agent 5865 mixed 1:10 with the 4306D solution will cover 2000 square feet per gallon. This yields a figure of $0.0390 per square meter. One pint to 1 quart of Liquid Lid is adequate for 20 gallons of 4306D solution. At one quart to 20 gallons, one gallon of Liquid Lid will be required for every 1488 square meters. The cost per square meter is, therefore, $0.0074. The total chemical costs per square meter are shown in Table A.1.5.2.

TABLE A.1.5.2. Total Chemical Costs for Foam Decontamination

Chemical	Cost (1982 $/m^2)
4306D	0.0363
5865	0.0390
Liquid Lid	0.0074
Total	0.0827

The foam could be applied with equipment very similar to the tank truck with pump and spray bar arrangement used for high-pressure water washing of pavement. For the purpose of applying foam, the spray bar or row of nozzles would be mounted across the rear bumper rather than the front. Since lower pressure and lower volume pumping are required, a smaller pump could be used. On the other hand, the nozzles must be such that they will mix the foaming agent with the acid-based decontamination chemical. Such nozzles must be manually set, but once set they seldom need readjustment. A ten-foot row of nozzles may require another person per truck in addition to the driver. Finally, separate tanks must be provided for the foaming agent and the decontaminant.

We estimate the capital cost and the operation and maintenance cost of this equipment to be ten percent higher than required for a high-pressure water wash. Also, we assume two people per truck will be necessary. Using the representative cost data described in the section on high-pressure water washing of pavement, we get $30.11 per hour for equipment. With two workers, the hourly labor cost comes to $39.50. The total hourly cost is $69.61.

If the truck applies foam at five miles per hour, the proper pump rate is 22 gallons per minute. At this rate a tank load will be sprayed in about three hours and 45 minutes. Estimating half an hour for refilling, about 1.5 tank loads can be applied in the seven production hours per eight-hour shift, the extra hour being set aside for equipment and personnel decontamination measures. This means that in an eight-hour shift there will be 5.6 hours of actual foam application time. The coverage will be:

$$5.6 \text{ hrs} \times 5 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$= 137{,}491 \text{ m}^2/\text{shift}$$

The average coverage per shift-hour will be 17,186 square meters. The cost per square meter will be:

$$\frac{\$69.61/\text{hr}}{17{,}186 \text{ m}^2/\text{hr}} = \$0.0041/\text{m}^2$$

As for removing the foam, mobile vacuumized street sweepers can be used. Their cost was calculated separately in Section A.1.1 dealing with vacuumized street sweepers. The rate of surface coverage for a vacuumized street sweep is one-half the rate of foam application. Thus, for each spray truck there would be two vacuumized street sweepers. The rate for the entire operation would be 17,186 square meters per hour.

Table A.1.5.3 summarizes the costs of chemicals, application, and removal. The last line of the table presents the combined costs based on these

TABLE A.1.5.3. Cost Summary of Foam Decontamination of Pavement

Item	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Materials
Chemicals					
4306D	--	0.0363	--	--	0.0363
5865	--	0.0390	--	--	0.0390
Liq. Lid	--	0.0074	--	--	0.0074
Total Chem.	--	0.0827	--	--	0.0827
Application	17,186	0.0041	0.0023	0.0018	--
Removal (2x)	8,632	0.0043	0.0021	0.0022	--
Total All Items	17,186	0.0911	0.0044	0.0040	0.0827

data. According to these figures, the great preponderance of cost lies with the chemicals.

A.1.6 Strippable Coating

Several manufacturers produce what is referred to as strippable (or peelable) coatings. These coatings can be sprayed on with a non-aspirated spray to a particular thickness. After drying, the material can be peeled off like cellophane tape. In addition to coatings that are physically or mechanically strippable, there are related coatings that can be removed with a chemical solution.

This material can perform three desirable functions. The first is that the material works as a fixative. On essentially any surface, the coatings will hold the contamination in place. The second function is that in removing the coating, much of the surface contamination is removed as well. The third function of this product is that it can be used to protect surfaces from contamination. By applying a coating before exposure to radiation, the radioactive particles can be prevented from becoming embedded in the surface. This last function is currently the most important one from a commercial standpoint. So-called "Grafitti Shield" is a chemically strippable coating.

The method of application can vary as long as a non-aerosol spray is used. Layers can be built up to the necessary thickness even if successive layers are allowed to dry before the application of the next layer.

Information on costs of strippable coating was supplied by Turco Products. The company sells three strippable coatings. Turco 5561 is pigmented yellow to facilitate complete removal. Turco 5931 is white and Turco 5931-C is clear. With a quantity discount, the material costs $16.48 per gallon. For use on smooth surfaces, one gallon would be appplied to 600 to 800 square feet. However, for asphalt roads and similarly rough surfaces, a thicker coating is necessary. This source recommends an application of a gallon for every 100 square feet. The material cost per square meter is

$$\frac{\$16.48/\text{gal}}{100\ \text{ft}^2/\text{gal} \times 0.093\ \text{m}^2/\text{ft}^2} = \$1.77/\text{m}^2$$

Using a tanker truck with pump and rear-mounted spray bar as described in Section A.1.3, the liquid could be applied at a vehicle speed of five miles per hour and pump rate of 44 gallons per minute. One 5000-gallon tanker load would keep the truck applying for about 110 minutes. Assuming 50 minutes for refilling the tank, and ignoring the problem of fractional tank loads, about 2.6 tank loads per shift could be applied, with about 4.8 hours of actual coating application. These calculations include one hour per shift allocated for equipment and personnel decontamination and reduced productivity. Total coverage per shift would be:

$$4.8\ \text{hrs} \times 5\ \text{mi/hr} \times 5280\ \text{ft/mi} \times 10\ \text{ft wide} \times 0.093\ \text{m}^2/\text{ft}^2$$
$$= 117{,}850\ \text{m}^2$$

One-eighth of that amount, or 14,731 square meters, is the average hourly production per shift hour.

Referring to the representative data for high-pressure water, we note that the total cost per hour is $47.11. This means that the cost of application per square meter is $0.0032. Labor's share is $0.0013 per square meter, and the equipment cost is $0.0019.

Any cost estimate for large-scale removal of peelable coating is highly conjectural since this has never been done before. A source at Turco suggested a method for large-scale, rapid, and economical removal of the coating. A pickup truck would be fitted with a front-mounted take-up spindle with electric motor drive. Ahead of this, two small circular knife blades at the end of metal arms would roll across the coated pavement, cutting the coating. The two blades would be about ten feet apart. Presumably this would allow a ten-foot wide strip of coating to be continuously lifted up from the pavement and rolled onto the take-up spindle.

Mike McCoy of Battelle Pacific Northwest Laboratories, Richland, Washington, is familiar with fixatives and strippable coatings. He said such a system might work but that it would probably require some experimentation before it became fully functional.

Assuming that this system could be made to work, but at a very conservative speed, we can estimate the cost of coating removal. The operation and maintenance cost of a pickup truck according to <u>Means Building Construction</u>

Cost Data 1982 is \$4.42 per hour plus a monthly rental cost of \$275. We assume that the modifications to the pickup truck increase its capital cost and its operation and maintenance cost by one third. On this basis, the cost of ownership is:

$$\frac{\$275/\text{mo} \times 4/3}{43 \text{ shifts/mo} \times 8 \text{ hrs/shift}} = \$1.07/\text{hr}$$

The cost of operation and maintenance is:

$$\$4.42 \times 4/3 = \$5.89$$

The total equipment cost is, therefore, \$6.96 per hour. Additionally, there is the cost of the driver and another worker at \$17.45 per hour each. The total hourly cost is then \$41.86, and for an eight-hour shift the cost would be \$334.88.

If this equipment can remove a strip ten feet wide at an average pace of one mile per hour, during the seven hours of production of an eight-hour shift, a total of 34,373 square meters will be removed. Over eight shift hours, this represents an hourly rate of 4297 square meters. Thus, the total removal cost per square meter for removal is \$0.0097. Labor would cost \$0.0081 per square meter, and equipment would cost \$0.0016 per square meter.

Table A.1.6.1 presents the preceeding information in summary form. Perhaps most striking is how costly the strippable coating is, relative to the other inputs. Since removal is the more costly procedure per square meter, the number of application crews is adjusted to conform to the removal rate. This means that 4,297 ÷ 14,731 = 0.29 application crews will be used for every removal crew. Thus, the inputs for this operation are 0.29 heavy-truck drivers, 0.29 5000-gallon spray trucks, two building laborers and one modificed pickup truck.

TABLE A.1.6.1. Summary of Cost and Productivity Data for Decontamination of Paved Surfaces with Strippable Coating

Item	Rate (m^2/hr)	Cost (1982 \$/m^2)			
		Total	Labor	Equipment	Materials
Chemicals	---	1.77	---	---	1.77
Application	14,731	0.0032	0.0013	0.0019	---
Removal (3.4x)	4,297	0.0097	0.0081	0.0016	---
Total	4,297	1.7829	0.0094	0.0035	1.77

A.1.7 Planing

Planing or grinding is a method of removing a surface layer of pavement. Planing machines are available in different sizes with different productivity rates. Some large "road profilers" can grind one lane wide, one inch deep, and advance at a rate of one mile per hour. These machines can be operated to remove essentially any thickness of pavement desired. They do so by abrading rather than by cutting the top surface off.

The Washington State Department of Transportation advises that equipment for a planing crew consists of one planer machine, a rotary broom mobile street sweeper, a front-end loader, and ten trucks for hauling away the debris. Many planers have conveyor systems to feed heavy debris directly into a dump truck. The personnel requirements are four equipment operators, one laborer, and ten truck drivers. However, when this method is used for decontamination, some additional equipment may be required.

While removing the top layer of pavement would generally seem like an effective way to remove the attendant contamination, the grinding action by which some planers operate creates a lot of dust. Newer planers spray the road surface with water to prevent excessive dust. Another way to limit resuspension of contaminants would be to treat the road surface with road oil, a sealer, or some other fixative. Still another possible method of dust control which two sources (Washington State Department of Transportation and Los Angeles Department of Public Works) agree may be effective is to contain the dust at the base of the planer with rubber skirts and to remove this dust with a high-power mobile vacuum hose intake. It is not clear if a standard vacuumized street sweeper would have adequate power and capacity. If not, then larger equipment such as a Super Sucker or Peabody mobile vacuum could be used. These machines are quite powerful. Power Master, Inc. in Portland, Oregon, which uses this type of equipment for contract industrial cleaning, provided information on these machines. The vacuum pumps on them are rated at 4,500 cubic feet per minute, and the dump box has an effective capacity of 12 cubic yards. They cost $160,000 new, and Power Master's rental rate, including the driver-operator, is $144.50 per hour. For continuous dust control operation, two vacuums per planer would be required. In some cases these vacuums may actually make some of the other pick-up equipment unnecessary.

The Washington State Department of Transportation estimates the cost of planing off one to 1.5 inches of asphalt at $1.00 per square yard, including rubble removal. Since the cost of hauling away contaminated materials is estimated separately in this report, it is necessary to remove the cost of hauling from the $1.00 per square yard cost. We assume that hauling comprises one half of the planing costs, giving a net planing cost of $0.50 per square yard. After adjusting for radiation control measures, the total costs is

$$\$0.50/\text{yd}^2 \times 1.196\ \text{yd}^2/\text{m}^2 \times 8/7\ \text{adj} = \$0.68/\text{m}^2$$

This source reports that their planers can cover three lane miles per eight-hour day. With seven hours of actual planing for every eight-hour shift, the average production per shift-hour is 1,611 square meters. In one shift the total production is 12,890 square meters.

Dust control for eight hours, using two high-power vacuums at \$144.50 per hour each, raises the daily cost by \$2,312. The cost per square meter at this rate is \$0.18.

The City of Los Angeles Department of Public Works said the major equipment necessary for a planing crew consisted of a planer, a skip loader, a dump truck, and a motorized sweeper. The personnel required included one planer operator, one loader operator, one truck driver, one sweeper operator, and two laborers.

The Department's cost for planing asphalt averages \$0.25 per square foot, which is equal to \$2.69 per square meter. However, for our purposes, it is necessary to remove the cost of the dump truck and driver, because hauling costs are handled separately. Here we assume that hauling away the rubble comprises 25 percent of the total cost. With the additional adjustment for radiation control measures, the cost per square meter is

$$(\$2.69/m^2 - 0.25 \times \$2.69/m^2) \times 8/7 \text{ adj.} = \$2.31/m^2$$

The Department's equipment will plane a width of six feet to a depth of one inch at a rate of one mile per hour. With seven hours planing per eight-hour shift, the average hourly production rate is 2,578 square meters. The added cost for dust control at this rate is \$0.11 per square meter.

Table A.1.7.1 summarizes the foregoing information. These data pose two principle difficulties. One is that the Los Angeles Department of Public Works cost per square meter is more than three times greater than that from the Washington State Department of Transportation. The second is that the implied cost per hour for both data sets is very high. The Washington State Department of Transportation data yield an hourly planing cost of \$1,095, and the hourly planing cost consistent with the Los Angeles Department of Public Works data is \$5,955. For comparison, the hourly cost of the inputs (without hauling) specified by the Washington State Department of Transportation can be estimated directly using data from Means Building Construction Cost Data 1982 and from data elsewhere in this report. This crew differs from the one specified by the Los Angeles Department of Public Works only by the inclusion of one additional laborer. This crew is described in Table A.1.7.2. The cost of the planer is estimated at \$100 per hour, since Means had no listing for that type of equipment. The cost of the street sweeper was taken from the representative cost data in Section A.1.1. The 2.25-cubic yard front-end loader is a medium-sized loader according to Means.

The three hourly cost estimates are summarized in Table A.1.7.3. The explanation for this wide discrepancy is not known. One possibility is that the Washington and Los Angeles sources include unspecified administrative, supervisory, engineering and support costs. Another possibility is that operation of the planer is much more costly that the estimated \$100 per hour. In general, the Means input costs seem reasonable, though it seems that a foreman (\$22.53 per hour) and a pickup truck (\$6.06 per hour) should be added, bringing the total hourly cost to \$330.58. However, at the coverage rates specified by the two other sources, the cost works out to \$0.21 per square meter or less, an amount which seems unreasonably low. Any resolution of these inconsistencies

TABLE A.1.7.1. Summary of Asphalt Road Planing Cost and Productivity

Procedure and Source	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment
Planing				
Wash. Dept. of Trans.	1,611	0.68	--	--
Dust Control				
Power Master	--	0.18	0.06	0.12
TOTAL	1,611	0.86	--	--
Planing				
L.A. Public Works	2,578	2.31	--	--
Dust Control				
Power Master	--	0.11	0.04	0.07
TOTAL	2,578	2.42	--	--

must be somewhat arbitrary. The approach used here is to make the major adjustment in the rate of coverage. We assume an hourly coverage rate of 750 square meters per hour, an hourly cost of $400.00, and a cost per square meter of $0.53. The cost per square meter is broken down between labor and equipment in the same proportion as the Means cost data in which $135.90 of $330.78 is for labor. Thus, the labor cost per square meter is $0.22 and the equipment cost is $0.31.

TABLE A.1.7.2. Hourly Cost Estimates of Inputs Specified by the Washington State Department of Transportation for Asphalt Road Planing

Input	Cost (1982 $/hr)
Labor	
3 Medium-equipment operators @ 24.95/hr (Means)	74.85
2 Building laborers @ $19.40/hr (Means)	38.80
Total Labor	113.65
Equipment	
1 Planer (est.)	100.00
1 Vac. street sweeper (Section A.1.1)	37.12
1 Front end loader, 2-1/4 yd^3 (Means)	51.70
Total Equipment	188.82
Total Input Cost	$302.47

TABLE A.1.7.3. Summary of Hourly Cost Estimates for Asphalt Road Planing

Source	Cost (1982 $/hr)
Sum of input costs	302.47
Washington State Department of Transportation	1,095.48
Los Angeles Department of Public Works	5,955.18

At a rate of 750 square meters per hour, dust control costs $0.38 per square meter. Of this amount, $0.13 is for labor and $0.25 is for equipment. Table A.1.7.4 summarizes this representative cost information. As can be seen, the total cost, including dust control, is $0.91 per square meter.

TABLE A.1.7.4. Representative Asphalt Road Planing Cost Data

Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment
Plane	750	0.53	0.22	0.31
Dust Control	--	0.38	0.13	0.25
TOTAL	750	0.91	0.35	0.56

A.1.8 Tack Coat

From the standpoint of radiation decontamination, there are three reasons to coat or resurface a road. The first is that a quickly applied thin coating may be desired as a fixative. The second reason is that a new surface will be required if the old one has been removed or planed. The third possible reason for resurfacing a road is that a new pavement layer over the existing contaminated pavement may provide sufficient shielding from the radiation, obviating the need for the actual removal of the radioactive particles.

As the reasons for surfacing a road are numerous, so too are the possible materials with which this can be accomplished. In addition to the basic materials with which roads are paved, asphalt and concrete, roads may also be coated with such materials as road oil, tar, tack coat, or slurry seal. In this and the next few sections, the costs and other important aspects of applying different surface coatings to pavement are discussed. First to be considered are minimum-thickness surface coatings. Second, thin-pavement coating data are presented. Finally, complete repaving is discussed.

Frequently the cost of applying some surface coating to a road is expressed in terms of the volume of the coating material. In part, this reflects the fact that materials make up the largest share of the total costs. The significance of this, with respect to the calculations being made for this report, is that costs are more closely tied to the unit of output than to time. Therefore, when considering that one hour in eight is allocated for personnel and equipment, the adjustments made to total cost may prove to be excessive.

Means' Site Work Cost Data for 1982 lists tack coat as the least costly of the seal coatings at \$0.34 per square yard. The crew for this operation consists of one foreman and two building laborers. The billing costs for these types of workers are \$22.25 and \$19.40, respectively. The total three-man crew costs \$61.05 per hour. The total cost per hour is found by multiplying the rate (525 square yards per hour) by the unit cost (\$0.34 per square yard), yielding \$178.50 per hour. Subtracting the labor cost from this amount gives the hourly material cost (\$117.45).

The given rate can be converted to square meters per shift-hour in the following manner:

$$\frac{4200\ \text{yd}^2/\text{day} \times 0.836\ \text{m}^2/\text{yd}^2}{8\ \text{hrs/day}} \times \frac{7}{8}\ \text{adj} = 384\ \text{m}^2/\text{hr}$$

Dividing the rate into the hourly costs gives the square-meter costs for total (\$0.46), labor (\$0.16), and materials (\$0.30). Means indicated no significant equipment for this operation. This probably accounts for the relatively low application rate.

According to the Washington State Department of Transportation, a "tack coat" is a thin layer of asphalt. This is sprayed on by a truck at 0.2 gallons per square yard, or 6 tons per lane mile. It is frequently used to bind one layer of asphalt to the next. At \$250 per ton (applied), the cost per lane mile is \$1500. The cost per square meter is:

$$\frac{\$250/\text{ton} \times 6\ \text{tons/mi}}{5280\ \text{ft/mi} \times 10\ \text{ft wide} \times 0.093\ \text{m}^2/\text{ft}^2} = \$0.3055/\text{m}^2$$

With seven hours operation per eight hours, the average coverage per shift hour is:

$$\frac{3\ \text{mi/hr} \times 7\ \text{hrs} \times 5280\ \text{ft/mi} \times 10\ \text{ft wide} \times 0.093\ \text{m}^2/\text{ft}^2}{8\ \text{hrs/shift}}$$

$$= 12{,}890\ \text{m}^2/\text{hr}$$

No information was provided by this source with respect to the costs for the various inputs; however, these can be estimated using Means data. The cost of a 3000-gallon distributor truck is given as \$31.12 per hour. The personnel required for this type of operation according to Means include one medium-equipment operator and one heavy-truck driver. The total billing costs for these workers are \$24.95 and \$19.75, respectively. The total is \$44.70. The hourly labor and equipment costs are easily converted to costs per square meter by dividing by the hourly coverage rate:

Labor: \$44.70/hr ÷ 12,890 = \$0.0035

Equipment: \$31.12/hr ÷ 12,890 = \$0.0024

Subtracting the square meter costs for labor and equipment from the total square meter costs leaves the cost per square meter of the material:

Material: \$0.3055 - (\$0.0035 + \$0.0024) = \$0.2996

The Means and the Washington State Department of Transportation data are summarized in Table A.1.8.1. As can be seen, the material costs are essentially identical. The major cost difference lies in the labor cost for Means as opposed to the very low labor and equipment costs for the Washington State Department of Tranportation. The obvious explanation for this difference lies in alternative methods of application. The Means data are for manual application as indicated by the relatively high labor costs and the low application rate. The Washington State Department of Transportation data, however, are for a high volume operation. The former method is appropriate for smaller, restricted areas, while the latter is appropriate for large paved areas, such as roads and parking lots. For this reason, the Washington State Department of Transportation data are taken as representative. Further, the Means data are taken as reperesentative for application to "other paved surfaces" (see Sections A.17 and A.18).

TABLE A.1.8.1. Summary of Data for Tack Coat Application to Asphalt Roads

Source	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Materials
Means	384	0.46	0.16	--	0.30
Wash. Dept. of Trans.	12,890	0.3055	0.0035	0.0024	0.2996

A.1.9 Sealer

The Los Angeles Department of Public Works occasionally applies a coating of slurry seal to asphalt. This material is an emulsified asphalt. It is mixed with sand and water and is described as looking like paint. For coatings that are to remain for some time without further treatment and that may be required to carry traffic loads, a sealer like slurry seal appears to be an attractive option.

Slurry seal is applied with a mobile slurry seal machine. Besides the slurry seal machine and its driver-operator, this operation also calls for a mixer-man, two asphalt rakers with hand tools, one laborer, and two or three trucks with drivers to keep the slurry seal machine supplied. Not necessary for radiation decontamination are workers and equipment for traffic control.

The daily coverage is 36 feet wide by one mile long. Adjusting for one hour per shift for radiation decontamination of equipment and personnel, the hourly coverage is:

$$36 \text{ ft wide} \times 5280 \text{ ft long} \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8 \div 8 = 1933 \text{ m}^2/\text{hr}$$

The cost of slurry seal applied is \$0.45 per square yard. This is equal to \$0.54 per square meter.

Coert Engelsman's 1981 Heavy Construction Cost File lists (p. 141) the total cost of surface preparation and application of surface sealer as \$0.82 per square yard. Labor accounts for \$.30 per square yard, equipment \$0.09 per square yard and materials \$0.43 per square yard. Total daily production is given as 1000 square yards. Considering no production for one hour per shift, the output per shift hour is

$$1000 \text{ yd}^2/\text{shift} \div 8 \text{ hrs/shift} \times 0.836 \text{ m}^2/\text{yd}^2 \times 7/8 \text{ adj} = 91 \text{ m}^2/\text{hr}$$

The adjusted cost per square meter can be found by multiplying the cost per square yard by the unadjusted hourly rate to get the hourly cost of labor and equipment. This is then divided by the adjusted hourly coverage in square meters. The unadjusted hourly coverage rate is

$$1000 \text{ yd}^2 \div 8 \text{ hrs/shift} = 125 \text{ yd}^2/\text{hr}$$

The labor and equipment costs are, therefore:

$$\text{Labor:} \quad \frac{\$0.30/\text{yd}^2 \times 125 \text{ yd}^2/\text{hr}}{91 \text{ m}^2/\text{hr}} = \$0.41/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$0.09/\text{yd}^2 \times 125 \text{ yd}^2/\text{hr}}{91 \text{ m}^2/\text{hr}} = \$0.12/\text{m}^2$$

Since the material cost per square meter is not affected by the hour lost per shift, the cost per square meter is calculated more simply:

$$\text{Material:} \quad \$0.43/\text{yd} \times 1.196 \text{ m}^2/\text{yd} = \$0.51/\text{m}^2$$

Adding the costs of the three inputs, the total cost per square meter is found to be \$1.04.

For comparison, the Engelsman data for tar and asphalt surface treatments are also given. Both of these coatings are applied at 1.5 gallons per square yard, and the coverage rate is listed at 1500 square yards for both. The adjusted hourly coverage rate is:

$$1500 \text{ yd}^2/\text{shift} \div 8 \text{ hrs/shift} \times 0.836 \text{ m}^2/\text{yd}^2 \times 7/8 = 137 \text{ m}^2/\text{hr}$$

Following the same calculations as for surface sealer, the square meter input costs for tar are calculated as shown:

Labor: $$\frac{\$0.13/\text{yd}^2 \times 187.5\ \text{yd}^2/\text{hr}}{137\ \text{m}^2/\text{hr}} = \$0.18/\text{m}^2$$

Equipment: $$\frac{\$0.06\ \text{yd}^2 \times 187.5\ \text{yd}^2/\text{hr}}{137\ \text{m}^2/\text{hr}} = \$0.08/\text{m}^2$$

Material: $\$1.00/\text{yd}^2 \times 1.196\ \text{yd}^2/\text{m}^2 = \$1.20/\text{m}^2$

Total: $\$0.18/\text{m}^2 + \$0.08/\text{m}^2 + \$1.20/\text{m}^2 = \$1.46/\text{m}^2$

The same cost calculations for asphalt are:

Labor: $$\frac{\$0.13/\text{yd}^2 \times 187.5\ \text{yd}^2/\text{hr}}{137\ \text{m}^2/\text{hr}} = \$0.18/\text{m}^2$$

Equipment: $$\frac{\$0.06\ \text{yd}^2 \times 187.5\ \text{yd}^2/\text{hr}}{137\ \text{m}^2/\text{hr}} = \$0.08/\text{m}^2$$

Material: $\$0.92/\text{yd}^2 \times 1.196\ \text{yd}^2/\text{m}^2 = \$1.10/\text{m}^2$

Total: $\$0.18/\text{m}^2 + \$0.08/\text{m}^2 + \$1.10/\text{m}^2 = \$1.36/\text{m}^2$

Comparing the Los Angeles Department of Public Works data with the Engelsman sealer data shows a considerable difference. The first source has a total cost of $0.54 per square meter versus $1.04 per square meter from the second source. The apparent explanation for this difference is in the method and scale of operation. This is reflected in the much higher rate reported by the Los Angeles Department of Public Works as compared to the one from Engelsman: 1,933 square meters per hour versus 91 square meters per hour.

There remains the problem of estimating the input costs for the Los Angeles Department of Public Works data. The first step is to estimate labor and equipment costs per square meter using hourly cost figures in Means' Building Construction Cost Data 1982 for the inputs specified by the Los Angeles Department of Public Works. The total hourly labor and equipment costs are estimated as shown in Table A.1.9.1. Means has no listing for labor costs for a mixer man or an asphalt raker. Their wage rates were estimated. Also, the hourly cost of a slurry seal machine was estimated using the hourly cost

TABLE A.1.9.1. Total Hourly Labor and Equipment Cost Estimates for Surface Sealing

	Cost (1982 $/hr)
Labor	
1 Driver-operator	24.95
2 Heavy-truck drivers @ $19.75	39.50
1 Mixer man (est.)	20.00
2 Asphalt rakers @ $20.00 (est.)	40.00
1 Building laborer	19.40
Total labor	143.85
Equipment	
1 Slurry seal machine (est.)	31.12
2 Nurse trucks @ $35.72	71.44
Total equipment	102.56

of a 3000-gallon distributor tank truck. The cost of a heavy dump truck was used for the cost of a nurse truck.

Dividing the hourly labor cost by the hourly coverage rate of 1933 square meters gives a cost of $0.07 per square meter for labor. The equipment cost is $0.05 per square meter.

Subtracting labor and equipment from the total cost per square meter leaves $0.42 per square meter for material. This is somewhat less than the cost specified by Engelsman and slightly less than similar surface coating

TABLE A.1.9.2. Summary of Surface Coating Data for Asphalt Roads

Source and Coating Type	Rate (m^2/hr)	Cost (1982 $/m^2) Total	Labor	Equipment	Material
L.A. Pub Wrks					
Sealer	1933	0.54	0.07	0.05	0.42
Englesman					
Sealer	91	1.04	0.41	0.12	0.51
Tar	137	1.46	0.18	0.08	1.20
Asphalt	137	1.36	0.18	0.08	1.10
Representative					
Sealer	1933	0.54	0.02	0.01	0.51

material costs specified by Means. The reason for this difference could be due to overestimation of combined labor and equipment costs, underestimation of total costs, or because material costs are in fact less per unit area than indicated by the published sources. Here it is assumed that, either because the Los Angeles Department of Public Works is able to acquire the material at a lower price or because of thinner application, this material cost estimate is reasonable.

A.1.10 Road Oil

Road oil would be appropriate as a temporary fixative preliminary to either planing or removal of existing pavement. There are other materials which could also be used as fixatives. These are described in Section A.7.1. According to the Washington State Department of Transportation, the cost of applying road oil is \$270 per ton. It is applied at 0.4 gallons per square yard at a speed of about three miles per hour with a swath about 12 feet wide. Since there are about 250 gallons of road oil per ton, the cost per square meter is

$$\frac{\$270/\text{ton}}{250\ \text{gal/ton}} \times 0.4\ \text{gal/yd}^2 \times 1.19599\ \text{m}^2/\text{yd}^2 = \$0.52/\text{m}^2$$

The rate of coverage is

$$3\ \text{mi/hr} \times 5280\ \text{ft/mi} \times 12\ \text{ft wide} \times 0.093\ \text{m}^2/\text{ft}^2 \times 7/8 = 15{,}468\ \text{m}^2/\text{hr}$$

Unfortunately, this source was unable to supply information regarding the separate costs of the various inputs.

While Means' Building Construction Cost Data 1982 does not include road oil application as a specific entry, an estimate of the cost of this operation can be developed from the Means volume. Page 11 gives the cost of a 3000-gallon distributor tank trailer with a 38-horsepower diesel motor to operate the pump. This distributor is for asphalt, but it is assumed that the cost of an oil distributor would not be greatly different. In addition, a truck tractor (p. 13) would also be necessary. The hourly cost of this equipment is calculated as shown in Table A.1.10.1. The rent in dollars per hour is based on 336 hours (2 shifts) per month.

TABLE A.1.10.1. Hourly Equipment Cost Estimate for Road Oil Distribution

Equipment	Oper. Cost (\$/hr)	Rent (\$/mo)	Rent (\$/hr)	Total (\$/hr)
Distributor	4.66	2500	7.44	12.10
Tractor	10.80	2350	7.00	17.80
Total				29.90

In addition, feeder trucks would be useful where the source of the material was not close. We estimate three feeder trucks per distributor. At \$25.00 per hour each, the total equipment cost is \$104.90 per hour.

For personnel, five driver operators are appropriate. The extra driver would be available for relief or for equipment operation on the distributor. The billing cost for heavy-truck drivers, according to Means, is \$19.75 per hour. Therefore, the total labor cost is \$98.75 per hour.

Following the information from the Washington State Department of Transportation, we assume an average vehicle speed of three miles per hour. The assumed application width is ten feet. The coverage rate is, then

$$3 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.0929 \text{ m}^2\text{/ft} \times 7/8 \text{ adj} = 12{,}890 \text{ m}^2\text{/hr}$$

Road oil costs \$0.31 per square meter. Multiplying this by the hourly coverage gives an hourly material cost of \$3995.90. Total cost comes to \$4199.55 per hour. Dividing each of the hourly cost categories by the hourly coverage gives the cost per square meter as shown in Table A.1.10.2. Because of their consistency with each other, these figures are taken as the representative costs for application of road oil. Table A.1.10.3 summarizes the information on the application of road oil.

TABLE A.1.10.2. Costs Per Square Meter for Road Oil Distribution

	Total	Labor	Equipment	Material
\$/hr	4199.55	98.75	104.90	3995.90
\$/m^2	0.3258	0.0077	0.0081	0.31

TABLE A.1.10.3. Summary of Road Oil Application Data for Asphalt Roads

Source	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Wash. Dept. of Trans.	15,468	0.52	--	--	0.31
Means	12,890	0.326	0.008	0.008	0.310
Representative	12,890	0.326	0.008	0.008	0.310

A.1.11 Thin Asphalt Overlay

Three sources provided information on the cost of placing a thin layer of pavement--one to two inches thick. Such a pavement layer is most likely to be applied after the road surface has been planed. When a new surface of asphalt is put on an asphalt base, the new asphalt is preceeded by application of a tack coat. Beyond its intended function to bind the two layers of asphalt, the tack coat also will fix any existing radiation on the road surface. While the cost of applying a tack coat was listed separately above, the following applications of asphalt on asphalt include the cost of a tack coat in the total.

The Policy Planning unit of the U.S. Federal Highway Administration provided selected data from a Federal Highway Administration publication entitled The Status of the Nation's Highways: Conditions and Performance, published in January, 1981. In Tables 4-4 through 4-8 the cost of resurfacing roads cross-tabulated by various factors was presented. For example, the cost per mile of resurfacing a one- to three-lane minor collector in a rural area on flat terrain was given as $69,000. In contrast, the cost of resurfacing a four-lane undivided highway in a built-up area is listed as $389,000 per mile. Using the Federal Highway Administration's estimate of 11 feet for lane width, the cost per square meter of resurfacing varied from $1.42 to $23.60. The former figure was for a minor collector on flat terrain in a rural area and includes six to eight feet of shoulder on each side of the road. The higher figure is for a pavement overlay on two lanes plus shoulders of an urban undivided highway in a built-up area. Neither the tables nor personal conversation made it quite clear why the cost of resurfacing a road was so highly variable and so sensitive to the type of area. Also, no data were available describing the inputs or the relative magnitudes of their costs. After adjusting for reduced productivity because of hazardous environment, these figures range from $1.62 to $26.97.

The State of Washington Department of Transportation reported that the cost of putting a one- to 1.5-inch layer of asphalt on existing pavement costs about $1.50 per square yard, or about $1.79 per square meter. In addition to this amount, the source advised that an extra ten percent should be included for "mobilization." This involves getting the equipment to the site and so forth. The cost, including the extra ten percent and one hour adjustment, is $2.25 per square meter.

This paving operation requires a mobile asphalt plant, a front-end loader, two tanker trucks to supply asphalt, a paving machine, three rollers, and ten trucks. The personnel required would be three operators for the asphalt plant and the loader, two teamsters for the asphalt supply trucks, five operators for the paving machine and the three rollers, ten drivers for the trucks, and two laborers.

According to this source, paving is about three times faster than planing, meaning that the speed for paving is nine lane miles per day. Adjusting for one hour per shift lost to radiation control activities, the average hourly production is:

$$9 \text{ mi} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8 \div 8$$
$$= 4834 \text{ m}^2/\text{hr}$$

The Los Angeles Department of Public Works reported that resurfacing costs $25.80 per ton of asphalt placed. This source added that a ton of asphalt will cover 160 square feet, one inch deep. This is a surface area of 14.88 square meters. Thus the cost per square meter, with productivity adjustment, is:

$$\frac{\$25.80/\text{ton}}{14.88\ \text{m}^2/\text{ton}} \times \frac{8}{7} = \$1.98/\text{m}^2$$

This source explained that their paving machine is capable of applying 600 tons of asphalt per hour. This represents about 1.8 lane miles per hour or, equivalently, 8928 square meters per hour. However, they cannot achieve this rate, since their asphalt plant only produces 1500 tons of asphalt per day. Even so, their actual paving rates do not fully utilize the asphalt plant's capacity. In a very good day, 1000 tons are applied. In a normal day, approximately 800 tons are applied. Adjusting for loss of a shift hour for special radiation control activities, 700 tons per day represents a better expectation for paving in a contaminated environment. This will cover slightly over two lane miles. The average coverage rate is 1302 square meters per hour.

Information taken from Means Site Work Cost Data 1982 (p. 75) and fromEngelsman's 1981 Heavy Construction Cost File (p. 140) were in close agreement, but differed significantly from cost data supplied by the Washington State Department of Transportation and the Los Angeles Department of Public Works. As can be seen in Table A.1.11.1, rates from Means and Engelsman are very close to each other but very much below the other two. Also, the costs reported in the two volumes are higher than the costs reported by the two governmental agencies. We can offer no explanation for the discrepancy.

Because the Means publication provides a relatively consistent set of data for this and other operations, and also because exactly the same sorts of adjustments are used for other operations, these adjustments are described in detail here. To apply an inch and a half thick layer of asphalt, Means calls for a crew consisting of one foreman at \$22.25 per hour (billing cost), seven building laborers at \$19.40 each, and two medium-equipment operators at \$24.95. The total hourly labor cost comes to \$158.05. The equipment required includes a paving machine which costs \$68.05 per hour and a ten-ton roller at \$20.51 per hour, bringing the total equipment cost to \$88.56 per hour.

TABLE A.1.11.1. Summary of Cost and Productivity Data for Paving Asphalt Roads with a One-Inch Layer of Asphalt

Source	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Materials
Fed. Hyw. Admin.	--	1.62 - 26.97	--	--	--
Wash. Dept. of Trans.	4834	2.25	--	--	--
L.A. Pub. Works	1302	1.98	--	--	--
Means	453	2.34	0.35	0.19	1.81
Engelsman	320	3.01	0.42	0.30	2.29
Representative	453	2.34	0.35	0.19	1.81

Multiplying the hourly production by the cost per square yard gives the total hourly cost:

$$\frac{3300\ yd^2/day}{8\ hr/day} \cdot \$2.87/yd^2 = \$1183.88/hr$$

Subtracting the hourly labor and equipment charge from this amount gives the hourly material cost:

$$\$1183.88 - (\$158.05 + \$88.56) = \$937.27$$

Next it is necessary to calculate the effective application rate in terms of square meters per hour. There are three adjustments to be made. One is to convert from square yards to square meters. The second is to adjust for one hour per shift lost to radiation control measures. The third adjustment is to convert the figures to reflect a pavement thickness of 1.0 inch rather than 1.5 inches. The method for dealing with this last adjustment becomes apparent when it is noted that there is a consistent relationship between different thicknesses of pavement, the rate of application, and the cost per square yard. Specifically, the Means data shows that doubling the pavement thickness results in halving the coverage rate and doubling the cost per unit area. Therefore, adjusting the application rate from 1.5-inch thickness to 1.0 inch requires multiplying by 1.5. Thus, the adjusted rate is

$$412.5\ yd^2/hr \times 0.836\ m^2/yd^2 \times 7/8 \times 1.5 = 453\ m^2/hr$$

The material cost per unit area is not subject to the one hour in eight adjustment for reduced productivity and decontamination. Therefore, to calculate the cost of material per square meter at one-inch thickness, the following steps are taken to convert the material cost per hour:

$$\frac{\$937.27/hr}{412.5\ yd^2/hr \times 0.836\ m^2/yd^2} \times \frac{1.0}{1.5} = \$1.81/m^2$$

The labor and equipment costs per square meter are calculated by simply dividing the hourly cost by the hourly production as shown:

$$\text{Labor:} \quad \frac{\$158.05/hr}{453\ m^2/hr} = \$0.35/m^2$$

$$\text{Equipment:} \quad \frac{\$88.56/hr}{453\ m^2/hr} = \$0.19/m^2$$

The total cost per square meter is the sum of the three input categories, or \$2.34 per square meter.

The disparity in the rates presents the greatest difficulty in specifying representative data for this operation. The Means data was selected as representative. There are several reasons for this. One is the consistency of this data with other operations in this report. Second is the internal consistency among the input categories. Further, the total per square meter is close to the average of all four data sources, and while the rate is somewhat lower than the average, it is one of the middle two rates reported. Moreover, the hazardous environment may make this rate more appropriate than the higher ones. Finally, this rate is consistent with the input costs per square meter in that the associated cost per hour is reasonable for the specified inputs.

A.1.12 Resurface

Resurfacing asphalt pavement involves two previously described operations: planing away the top surface, followed by paving with a one-inch layer of asphalt. Paving is the faster and also the more costly procedure. Adjusting the scale of the planing step to that of paving requires 2837 ÷ 750 = 3.78 planing crews for every paving crew. The costs per square meter of the combined operation are simply the sum of the costs of the separate operations. Table A.1.12.1 summarizes this discussion.

TABLE A.1.12.1. Summary of Asphalt Road Resurfacing Data

Procedure	Crews	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Plane	3.78	750	0.91	0.35	0.56	--
Pave	1	2837	2.02	0.11	0.10	1.81
Total	1	2837	2.93	0.46	0.66	1.81

A.1.13 Medium-Thickness Asphalt Overlay

In Section A.1.11 the representative cost of paving asphalt with a one-inch layer of new asphalt was developed. The basis for these figures was primarily information from the Washington State Department of Transportation and the Los Angeles Department of Public Works and, to a lesser extent, Means' Building Construction Cost Data 1982. These sources were also used to develop a consistent estimate of representative costs and the rate for paving a three-inch layer of asphalt.

Data in Means (p. 47) indicates that the costs and rate of paving remain constant with the volume of pavement applied. Thus, doubling the pavement thickness will halve the application rate and double the cost per unit area. Using this relation, the costs and rate developed in Section A.1.11 for paving a one-inch layer can be transformed to a three-inch layer. The results are summarized in Table A.1.13.1.

An overlay of asphalt will reduce measurable radiation by shielding and preventing resuspension. Without any actual removal of radioactive particles, a three-inch layer of asphalt will reduce emitted radiation by half.

TABLE A.1.13.1. Representative Data for Paving Asphalt Roads with a Three-Inch Layer of Asphalt

Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Materials
946	6.06	0.33	0.30	5.43

A.1.14 Removal and Replacement

Means Site Work Cost Data 1982 (p. 22) lists the cost of removing asphalt pavement at $2.23 per square yard, using one equipment operator to run both a backhoe and a hydraulic demolition hammer, plus two laborers. Labor makes up 51 percent of the costs excluding overhead, or 40 percent of total costs, while equipment accounts for 49 percent of the costs excluding overhead and profit and 39 percent of costs including overhead and profit.

The production rate is listed at 390 square yards per day. With one hour per shift lost for radiation control, the average hourly production is 35 square meters. The cost per square meter is $3.05.

Means (p. 75) lists asphalt paving costs for thicknesses up to four inches. To standardize to a thickness of six inches, costs were adjusted upward by twice the amount that costs increased from three to four inches. Specifically, costs in 1982 dollars per square yard were given as shown in Table A.1.14.1.

TABLE A.1.14.1. Means Cost Data for Asphalt Paving

Thickness	Cost (1982 $) Material	Labor	Equip.	Total	Total, incl. Overhead & Profit
3"	3.80	.70	.40	4.90	5.60
4"	5.10	.97	.54	6.61	7.60
6" (est)	7.70	1.31	.82	9.83	11.60

Total cost rose by $2.00 per square yard when thickness was increased by one inch from three to four inches. This cost per inch was applied to the increase of two inches from four to six. Thus $4.00 were added to the $7.60 listed for the four-inch thickness, bringing the total to $11.60 per square yard for a six-inch thickness. Other cost categories were adjusted in a similar manner. The cost per square meter is $13.87. The production rate was estimated at 550 square yards per day. After adjustments, this comes out to 50 square meters per hour and a unit cost of $15.85 per square meter.

Engelsman's 1981 Heavy Construction Cost File (p. 56) estimates the cost of removing asphalt paving over six inches thick at $0.82 per square yard. Adjusting the daily output of 1000 square yards by 7/8, the implied average hourly production is 91 square meters. The adjusted cost is $1.12 per square meter. The cost breakdown is 40 percent for labor and 60 percent for equipment.

The State of Washington Department of Transportation estimates the cost of removing six inches of asphalt pavement at $2.50 per square yard. With adjustments, this implies a cost of $3.42 per square meter. To replace the same surface costs $8.75 per square yard. The same adjustments bring the cost per square meter to $11.96.

The City of Los Angeles Department of Public Works lists a combined removal and replacement cost as $45.70 per ton of asphalt placed. They further estimate asphalt placement costs at $25.80 per ton. The difference, $21.70 per ton, refers to the volume of material removed. Since a ton of asphalt occupies 13.33 cubic feet, these costs refer to an area of 26.66 square feet of pavement six inches thick. These figures are equivalent to $7.32 per square yard for removal. After adjustments, this comes to $10.01 per square meter. This figure is clearly much higher than those given previously. No explanation can be offered for this difference.

The paving cost at $25.80 comes to $11.90 per square meter after adjustments.

The Federal Highway Administration supplied data in the form of selected tables from The Status of the Nation's Highways: Conditions and Performance. As mentioned previously in the discussion of applying a thin pavement overlay, these data consist of widely varying unit costs that generally seem to be much higher than costs supplied by other sources. Further, these data apply to all road construction materials. The combined costs for removal and replacement run from $8.34 per square meter for a rural minor collector four lanes or more wide on flat terrain, to $112.49 per square meter for two lanes' width of an urban freeway in a built-up area. These figures have been adjusted to account for radiation control measures.

The representative unit cost of removal was calculated as the average of the asphalt removal costs, excluding those for the Los Angeles Public Works Department. All of the replacement costs were averaged to get the representative cost. Representative input costs are based on the percentage of total costs for the inputs as reported by Means and Engelsman. These percentages were averaged between the two sources, and then the average percentage was applied to the corresponding representative total cost. Representative production rates are averages of the reported rates. The representative cost data for concrete surfaces are all calculated as averages. The rate for the combined removal and replacement operation is set at 71 square meters per hour, the rate of the more costly replacement procedure. This implies that there will be 71/63 = 1.13 removal crews per replacement crew.

TABLE A.1.14.2. Summary of Pavement Removal and Reconstruction Cost and Productivity Data

Source Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Materials
		ASPHALT SURFACES			
Means					
Removal	35	3.05	1.22	1.83	--
Replacement	50	15.85	2.06	3.17	10.62
Total		18.90	3.28	5.00	10.62
Englesman					
Removal	91	1.12	0.45	0.67	--
Replacement	91	11.78	1.65	0.94	9.19
Total		12.90	2.10	1.61	9.19
Wash. Dept. of Trans.					
Removal	--	3.42	--	--	--
Replacement	--	11.96	--	--	--
Total	--	15.38	--	--	--
L.A. Pub. Works					
Removal	--	10.01	--	--	--
Replacement	--	11.90	--	--	--
Total	--	21.91	--	--	--
Representative					
Removal	63	2.53	1.01	1.52	--
Replacement	71	12.87	1.67	1.80	9.40
Total	71	15.40	2.68	3.32	9.40

A.2 CONCRETE ROADS

Most of the operations for concrete roads are the same as for asphalt roads. Therefore, for many of the operations on concrete roads, the reader is directed to the section describing the corresponding operation on asphalt roads. Where significant differences exist, they are noted.

A.2.1 Vacuum

The vacuuming of concrete pavement is the same as vacuuming asphalt pavement. See Section A.1.1.

A.2.2 Low-Pressure Water Wash

A low-pressure water wash of concrete pavement is the same as a low-pressure water wash of asphalt pavement. See Section A.1.2.

A.2.3 High-Pressure Water Wash

A high-pressure water wash of concrete pavement is the same as a high-pressure water wash of asphalt pavement. See Section A.1.3.

A.2.4 Very High-Pressure Water Wash

A very high-pressure wash of concrete pavement is the same as a very high-pressure wash of asphalt pavement, except that concrete pavement is less likely to be eroded by this procedure. See Section A.1.4.

A.2.5 Foam

See Section A.1.5.

A.2.6 Strippable Coating

See Section A.1.6.

A.2.7 Planing

Planing is described in Section A.1.7. According to the Los Angeles Department of Public Works, planing concrete takes about 20% more time than planing asphalt. Therefore, the representative asphalt planing data from Section A.1.7 are adjusted to account for this slower rate, holding hourly costs constant. The rate for planing concrete is 625 square meters per hour. The total cost is $1.09 per square meter, of which labor accounts for $0.42 and equipment accounts for $0.67.

A.2.8 Tack Coat

See Section A.1.8.

A.2.9 Sealer

See Section A.1.9.

A.2.10 Road Oil

See Section A.1.10.

A.2.11 Thin Asphalt Overlay

Currently, asphalt is the preferred paving material over concrete in most situations. While a new asphalt surface on an existing asphalt base generally poses no particular difficulties, asphalt surfacing on a concrete base could. Because concrete is rigid, cracked concrete can rock as the vehicle load moves across it. This rocking can result in the breaking up of an asphalt coating unless the coating is fairly thick. For this reason, the Los Angeles Public Works Department never uses less than two inches of asphalt on a concrete base. On the other hand, the State of Washington Department of Transportation reported that they maintained their minimum thickness of an asphalt overlay on concrete at 1 to 1.5 inches, the same as over an asphalt base.

In this report it was assumed that a minimum of two inches of asphalt pavement would be required when laid over a concrete base. As mentioned in Section A.1.11, data in Means' Building Construction Cost Data 1982 show that doubling the pavement thickness results in doubling the cost per square meter and halving the coverage rate. The costs and rate for paving over concrete were estimated using this relationship applied to the representative data for paving over asphalt. Therefore, the rate is 1419 square meters per hour and the total cost per square meter is \$4.04. This total breaks down into \$0.22 for labor, \$0.20 for equipment, and \$3.62 for material.

A.2.12 Resurface

As with resurfacing asphalt (see Section A.1.12), resurfacing concrete involves planing followed by an application of a thin layer of asphalt. The only differences between resurfacing concrete and asphalt are that planing concrete takes longer than planing asphalt and that a thicker pavement layer is necessary on concrete. Resurfacing as a single operation therefore amounts to combining planing and paving. This is shown in Table A.2.12.1. The rate for

TABLE A.2.12.1. Summary of Concrete Road Resurfacing Data

Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Plane	625	1.09	0.42	0.67	--
Pave	1419	4.04	0.22	0.20	3.62
Total	1419	5.13	0.64	0.87	3.62

the combined operation is set at that of the more costly step, paving. This means that 1419 ÷ 625 = 2.27 planing crews would be used for every paving crew.

A.2.13 Medium-Thickness Asphalt Overlay

See Section A.1.13.

A.2.14 Removal and Replacement

See Section A.1.14 for a general discussion of removal and replacement of pavement. The data collected and the representative data are shown in Table A.2.14.1.

A.3 ROOFS

The techniques for decontaminating roofs include vacuuming, low-pressure water flushing, high-pressure water flushing, sandblasting, foam, strippable coating, and removal and replacement. Since most of these procedures are not performed on a regular commercial or other basis, the estimates pertaining to them are not as strong as they otherwise would be.

Roofs vary considerably with respect to such aspects as height, slope, construction material, presence or absence of rain gutters, and area. The types of roofs and their setting considered here are usually residential roofs one to two stories high with a slight pitch. Other roof types are also explicitly considered. Note that height may not translate directly into difficulty. Higher roofs are generally built with accomodation for access, either inside or outside the structure. Such roofs may also have fire mains and other features conveniently located.

A.3.1 Vacuuming

Vacuuming has the advantage of removing radioactive particles without causing extensive damage to the surface and without creating a new problem such as a large volume of contaminated water. Two commercial sources, out of several contacted, responded that they do or would vacuum roofs.

American Maintenance Systems in Seattle, Washington performs custodial duties on a contract basis. They said that although they do not regularly vacuum roofs, they could and would if hired to do so. The method would be to supply a worker with an aluminum extension ladder and a portable vacuum of the sort that can be strapped on the back. This equipment costs about $200. In some cases, the worker may be provided with a cannister vacuum with 100 feet of hose. This vacuum could cost from $100 to $500. In general, this procedure has very low equipment requirements. If total initial capital cost per worker is $600 and if the equipment is reasonably durable, then a charge of about $1.50 per hour for capital would be adequate. Figuring labor at $17.45 per hour puts the total hourly cost at $18.95.

This source estimated that a 1,000 square foot roof could be vacuumed in 45 minutes. Adding 15 minutes for moving to the next roof gives an average

TABLE A.2.14.1. Summary of Pavement Removal and Reconstruction Cost and Productivity Data

Source Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
		CONCRETE SURFACES			
Means					
Removal	23	4.66	1.86	2.80	--
Replacement	182	18.93	0.95	3.03	14.95
Total	134	23.59	2.81	5.83	14.95
Englesman					
Removal	69	2.40	1.22	1.18	--
Replacement	160	13.25	0.93	0.53	11.79
Total	144	15.65	2.15	1.71	11.79
Representative					
Removal	46	3.53	1.54	1.99	--
Replacement	171	16.09	0.94	1.78	13.37
Total	171	19.62	2.48	3.77	13.37

rate of 1,000 square feet per hour. With one hour per every eight-hour shift set aside for equipment and personnel radiation decontamination, the estimated total coverage in one shift is 7,000 square feet. Converting to square meters per shift-hour, we get an average production rate of 81 square meters per hour. The average unit cost is:

$$\frac{\$18.95/\text{hr} \times 8 \text{ hrs}}{7{,}000 \text{ ft}^2 \times 0.093 \text{ m}^2/\text{ft}^2} = \$0.23/\text{m}^2$$

Power Master, Inc. in Portland, Oregon, operates large high-power mobile vacuums for contract jobs. This equipment is quite powerful and could be inappropriate for use on some roofs. The rental of the machinery, including operators, is $144.50 per hour. The company is occasionally hired to vacuum roofs. Its charge for doing this is between $10 and $16 per 100 square feet.

Using the average Power Master charge for 100 square feet avoids the necessity of adjusting for nonproductive time because this charge includes compensation for periods without production. These occur because the company carries an inventory of extra equipment to handle load fluctuations, thus, the cost per unit area is

$$\frac{\$13/100 \text{ ft}^2}{100 \text{ ft}^2 \times 0.093 \text{ m}^2/\text{ft}^2} = \$1.40/\text{m}^2.$$

Power Master supplied no information on the rate of surface treatment.

The Power Master cost comes to nearly ten times the American Maintenance figure. This is, of course, directly related to the heavy capital intensity with Power Master's big mobile vacuum. The American Maintenance Systems-based cost estimates seem reasonable, and they are taken as a representative estimate of the cost of vacuuming roofs. Labor constitutes 92 percent of the costs of this operation, with the remaining eight percent going to equipment.

A.3.2 Low-Pressure Water Flushing

The simplest way to accomplish a low-pressure hosing of roofs is to equip each worker so engaged with two to four sections of garden hose, a spray nozzle and an aluminum extension ladder. The hose would be attached to the structure's existing water mains and operated at standard water pressure. The time to hose a roof would be about the same or slightly faster than the time to vacuum it. Here we assume 45 minutes per 1000 square foot roof, plus 15 minutes to move to the next roof. With seven hours productive work in an eight-hour shift, 7000 square feet or 651 square meters of roof will have been treated. The average hourly production will be 81 square meters.

For this procedure, each worker would be equipped with relatively little capital. Hoses, ladder, and so forth would amount to not more than $200. As a rough approximation, we can budget one dollar per hour for capital, bringing total hourly costs to $18.45. Adjusting for one hour per shift for radiation control, the unit cost is $0.23 per square meter. Labor comprises 95 percent of the costs and equipment five percent.

While this method has good removal efficiency with respect to its cost, the resulting contaminated water could pose a problem. Depending on the conditions, it may be acceptable to allow the water to percolate into the soil, or it may be sufficient to direct the runoff into the storm sewers. In more severe instances, it may be necessary to collect the water using rain gutters and drain spouts, or it may be unwise to use water at all.

A.3.3 High-Pressure Water

Water at pressures in the range of 80 to 120 pounds per square inch provide good scouring to remove embedded radioactive particles. However, this pressure is high enough so that it would be possible to cause damage to the roofs. Hosing upward against the lay of shingles could rip them off. For this reason it is generally necessary to direct the stream of water down on the roof. In most cases this requires someone to be on or above the roof.

A relatively simple method to accomplish this task is to use a method similar to that described for low-pressure hosing of roofs. The basic equipment is again hoses, but this time fire hoses capable of delivering water to the nozzle at sufficiently high pressure are used. However, in this case the weight, rigidity, and back pressure on the hose make it unwieldy enough so that two or three people per hose would be required.

Some data on the productivity of hosing roofs has been compiled from actual experience. The Administrative Services Manager of Spokane Community College in Spokane, Washington, directed the cleanup of the campus following the 1980 eruption of Mount St. Helens. That catastrophic event covered all exterior surfaces with a layer of volcanic ash. Roofs were cleaned by firehosing. They found that the average productivity was 7,500 square feet per man-hour. However, this rate was achieved on large, institutional-sized buildings. Not so much time was spent shifting from one roof to another and shifting from one hydrant to another. Further, the data on decontamination efficiency do not indicate the amount of water necessary to achieve the stated removal percentages. In general, one would expect that in terms of actual hosing time, high-pressure hosing would take no longer and might be somewhat faster than low-pressure hosing. On the other hand, moving from one roof to another may take somewhat longer, even with the extra manpower, due to the weight and stiffness of the hose as well as the wider spacing of hydrants.

On the basis of these considerations, we estimate a rate almost identical with that for low-pressure hosing: 40 minutes for a 1,000 square foot roof and 20 minutes to move from roof to roof. The production in an eight-hour shift would be 7,000 square feet after including time for equipment and personnel radiation protection measures. Again, the average coverage per hour would be 81 square meters.

The costs would include those for labor and for equipment. Here we assume three-man crews, giving a labor cost of $58.35 per hour. In addition, there are the costs for a ladder and hose. The length of hose necessary depends on the spacing of the hydrants. If hydrants are placed every other block, then they will be somewhat more than 600 feet apart. This suggests that hosing crews should have sufficient hose to cover everything in a radius of more than 300 feet. We estimate that 500 feet of 1-1/2-inch hose, ten sections of 50 feet each, should be enough for the average crew. Referring to the costs in Table A.1.3.1, we see that the hose sections, with couplings, will cost $550 in constant 1982 dollars. With nozzle and other miscellaneous fire equipment, the cost will come to about $600. With the ladder, the total will be about $675.

According to the source at Yakima Community College, the hoses wore out after two weeks of continual use. It is not clear if that equipment was in good shape to begin with or if the usage to which it was put was especially hard or easy. Taking the wear factor into consideration, we estimate equipment costs at $2.00 per hour.

Total costs, then, are $60.35 per hour, or $0.74 per square meter. Labor, of course, accounts for nearly all of this cost - 97 percent. Equipment makes up the remaining three percent.

In the event that high pressure water mains are not available, a pumper truck would be necessary to operate the required water pressure. Referring to the additional cost that this equipment entailed for high pressure hosing of pavement, we estimate that the increase in cost for hosing roofs would be about $1.60 per square meter. This figure is based on the hourly cost of the pumper at $130 divided by the coverage rate of 81 square meters per hour.

Other options for high-pressure hosing of roofs include using fire department ladder trucks or mobile man lifts. This equipment would not reduce labor costs but would substantially increase hourly equipment costs. Further, actual hosing time would not be substantially reduced. Therefore, if there is to be a gain by using such equipment, it would have to come from reducing the time it takes to move from one roof to the next, or from a high premium on quick decontamination of roofs.

A.3.4 Sandblasting

The abrasive action of either wet or dry sandblasting can be very effective in removing embedded radioactive particles. However, two factors can severely limit this effectiveness. The first of these has to do with the material being blasted. Blasting tar or composition surfaces can actually drive some of the contamination into the material. This becomes more likely at higher temperatures. The second limitation is that both wet and dry sandblasting tend to spread the radiation to other surfaces. With wet blasting there is the problem of contaminated water and sand. With dry blasting the resultant dust will contaminate other surfaces and recontaminate surfaces just cleaned.

A possible solution to this is vacuum blasting. The dry sandblasting nozzle is surrounded by a cone which is attached to a vacuum. The result is that the dust and sand created by the blasting is immediately vacuumed away. The drawback is that the vacuum greatly weakens the blasting action and the amount of blasted sand has to be reduced. Vacuum blasters cover a strip about 0.75 inches wide. Daily coverage of 40 to 50 square feet per day is considered quite good. The result is that it is generally less costly to replace the roof than to vacuum blast it. This and the following information come from Oliver B. Cannon & Son of Richland, Washington. This firm has experience at the Hanford Nuclear Reservation in sandblasting for radiation cleanup.

The basic equipment required for sandblasting includes a truck with an air pump with a capacity of 185 to 200 cubic feet of air per minute, a two hundred pound pot of sand, two 100-foot hoses with nozzles, and miscellaneous equipment including hoods and so forth for the two-man crew.

Normal daily production when done on a continuous basis is 2000 square feet in eight hours. If the average roof is about 1000 square feet in area, and it takes 20 minutes to shift from one roof to the next, then it will take a total of eight hours and 40 minutes to blast 2000 square feet. Converting to square meters per hour and adjusting for one hour per shift for radiation control measures this operation can be done as follows:

$$\frac{2000\ \text{ft}^2}{8\frac{2}{3}\ \text{hrs}} \times 0.0929 \times \frac{7}{8} = 19\ \text{m}^2/\text{hr}$$

The cost for dry blasting runs about \$0.20 to \$0.30 per square foot for light application. Using a figure of \$0.35 per square foot for a heavier application, and adjusting the cost upward to account for one hour per shift lost to equipment and personnel radiation protection measures, we get a cost of \$0.40 per square foot, which equals \$4.30 per square meter. Wet blasting costs 10 to 15 percent more than dry blasting. Using an average 12.5 percent increase, the cost per square meter for wet blasting is \$4.84 per square meter. Neither of these cost figures includes any allowance for dust control or water treatment.

The wet blast cost is taken as representative since this method is more likely to be used. Blasting from the top down on a sloped roof will leave the roof decontaminated, and the water and sand by-product can be left on the ground to allow the radiation to leach into the soil or may be picked up by another method.

The cost shares may be approximated in the following way. The cost per shift for sandblasting varies from about \$400 to \$800 per shift depending on whether it is wet or dry blasting and depending on whether a light or more thorough coverage is achieved. Labor cost for the two workers will be somewhat higher than the assumed base wage rate of \$17.45 due to the special equipment operating skills required. If we assume a labor cost of \$20 per worker, labor's share of the cost is somewhere in the range of five to ten percent. The latter figure seems more consistent with others derived, so it is taken as representative. Remaining costs are for equipment.

A.3.5 Fixative

Like several other operations, application of a fixative involves spraying the surface with some chemical mixture using paint spraying or similar equipment. The estimation of the cost for such an application procedure to roofs is discussed in Section A.3.7. Fixatives and their characteristics are explained in Section A.7.1. Of the fixatives discussed, Compound SP-301 appears to be an appropriate choice for use on roofs.

If it is not necessary to strictly confine the applied fixative to the roof surface, it can be applied with a device such as a hydroseeder. This is a mobile tank truck equipped to spray liquids to areas adjacent to roads. It is typically used by highway departments for seeding areas next to roads and for other liquid treatments of roadside surfaces. According to the Washington State Department of Transportation, a hydroseeder has the capability of covering an acre per hour with the required coating of 0.4 gallons per square yard. This works out to a 32 gallon per minute pump rate. A hydroseeder might be used to apply fixative to roofs if lawns are to be coated with fixative and if building sides are to be replaced. The estimated cost of application by this method, excluding the cost of the fixative, is $1.19 per square meter, the same cost as applying fixative to lawns. The calculations for this cost estimate are explained in Section A.4.5.

It is more likely, however, that a carefully confined application of fixative will be required. This could be accomplished using mobile sprayers of the sort described for the application of foam and strippable coating of roofs. Minor modifications probably would be necessary so that a non-aerosol spray could be used, though this should not have any significant impact on the estimated costs of this method of application. Therefore, the previously estimated cost of $0.99 per square meter for application will be used in this case, as well. To this must be added the cost of the fixative which was calculated elsewhere at $0.23 per square meter. This brings the total cost of applying fixative to $1.22 per square meter. Again, this operation requires two workers and a spray truck with miscellaneous equipment such as ladders, hoses, and so forth.

A.3.6 Foam

The basics of foam decontamination technology were described in Section A.1.5. In that section, the cost per square meter for chemicals was calculated as $0.083. To this cost need to be added the costs of application and removal.

Mobile sprayers of the sort used for commercial lawn, shrub, and tree spraying or paint sprayers appear to have the capability to apply decontamination foam. Acording to commercial lawn spraying services such as A-Z Pest Control in Richland, Washington, and Roger's Spray and Tree Service in Seattle, Washington, these trucks have a capacity of around 300 gallons and the ability to deliver an aerosol spray at the rate of 32 gallons per minute.

A-Z Pest Control's normal charges are about $80 per hour for labor and equipment. With two workers per truck, equipment accounts for about $45, or 56 percent of the total. However, the source added that the hourly charge would probably be lower if they could operate on a continuous basis. Therefore, this figure should be adequate for any equipment modifications that might be required.

Assuming 45 minutes per 1,000 square foot roof and 15 minutes to move from one roof to the next, the average daily production during seven out of eight hours would be 7,000 square feet. This works out to 81 square meters per hour. The cost of application per square meter, including labor is, then:

$$\frac{\$45/\text{hr} + \$35/\text{hr}}{81\ \text{m}^2/\text{hr}} = \$0.99/\text{m}^2$$

The cost of labor per square meter is

$$\frac{\$35/\text{hr}}{81\ \text{m}^2/\text{hr}} = \$0.43/\text{m}^2$$

The cost of equipment as calculated similarly is

$$\frac{\$45/\text{hr}}{81\ \text{m}^2/\text{hr}} = \$0.56/\text{m}^2$$

Removal of the foam would require a large-capacity vacuum. The solution here seems to be to fit a fairly long extension onto the hose intake of a mobile vacuumized street sweeper. We assume the same vacuuming production rate here as estimated for vacuuming roofs without foam - 81 square meters per hour. As for the cost of this vacuuming, we first convert the representative total cost of mobile street vacuuming to a cost per hour.

$$8{,}777\ \text{m}^2/\text{hr} \times \$0.0043/\text{m}^2 = \$37.74/\text{hr}$$

Then this amount is divided by the average hourly area vacuumed to give the cost per unit area:

$$\frac{\$37.74/\text{hr}}{81\ \text{m}^2/\text{hr}} = \$0.47/\text{m}^2$$

To this we add the cost of an additional worker at \$17.45 per hour:

$$\frac{\$17.45/\text{hr}}{81\ \text{m}^2/\text{hr}} = \$0.215/\text{m}^2$$

To find the total cost of the foam treatment to roofs, we add the costs of the separate parts. This brings the total to \$1.54 per square meter. These data are summarized in Table A.3.6.1.

TABLE A.3.6.1. Summary of Cost and Productivity Data for Foam Decontamination of Roofs

Item	Rate (m^2/hr)	Cost (1982 $\$/m^2$)			
		Total	Labor	Equipment	Materials
Chemicals	---	0.08	---	---	0.08
Application	81	0.99	0.43	0.56	---
Removal	81	0.66	0.43	0.23	---
Total	81	1.73	0.86	0.79	0.08

A.3.7 Strippable Coating

The essentials of strippable coating as a decontamination method were described in Section A.1.6. The cost for using this technique on roofs is calculated much as the costs for foam decontamination were calculated in the previous section.

In Section A.1.6, the cost of the chemic for strippable coating was estimated at $1.77 per square meter. To this amount must be added the costs of application and removal. Again, a modified mobile landscape spray truck or paint spraying equipment, as was suggested for application of foam to roofs, could be used for applying strippable coating as well. The pump and nozzle apparatus would have to be modified to produce a non-aerosol spray, but even with these modifications a charge of $45 per hour for equipment should be adequate. With two workers the total cost of application would be $80 per hour and $0.99 per square meter.

The cost of removing the coating is hard to estimate without some data on that sort of operation. It is not clear if in pulling the coating up, shingles would come loose. According to a source at Turco Products, this material is very easy to remove and removal can be done quickly, but such a description must be tempered with the caveat that there is little or no experience in this operation.

Removing the strippable coating from roofs would be basically a hand operation. A worker would use a knife to make sufficient cuts in the film so that it could be pulled off easily. The sheets of coating would be thrown on the ground for later pickup and disposal. We assume two man-hours to strip a roof and move to the next one - about twice as long as to vacuum it. In addition, we estimate ten minutes of pickup-truck (or other small or medium truck) time per roof to load the stripped coating which had been thrown on the ground.

Using the base labor charge, the cost of labor per shift for stripping would be $140. To this we add the cost of incidental equipment such as knife and ladder. One dollar per hour would cover this, so the shift total for incidental capital would be $8 and the shift total for removing the coating would be \$148. Assuming 3.5 roofs, or 3,500 square feet, stripped per shift, the average hourly coverage is 41 square meters. The unit cost is:

$$\frac{\$148/\text{shift}}{3{,}500\ \text{ft}^2/\text{shift} \times .093\ \text{m}^2/\text{ft}^2} = \$0.45/\text{m}^2$$

Almost all of this cost - 95 percent - is for labor. Only 5 percent is for equipment.

Disposal of the removed strippable coating would be handled in two steps. Pickup trucks would collect the strippable coating from the sites where the coating was used and transport the material to a central collection point where larger trucks would be loaded for hauling to the final disposal site. In this way, the more costly larger trucks could be used more effectively through quicker loading. For strippable coating, it may be desirable to use garbage trucks with hydraulic compression equipment to reduce the volume of material. If these trucks were used, the pickup trucks would not be necessary.

The cost of a pickup is estimated from Means' Building Construction Cost Data for 1981. The monthly rental cost is listed at \$275, and the hourly operating cost is \$3.94. Adding the cost of the driver and assuming 43 shifts per month, the cost per shift for the truck and driver is:

$$\frac{\$275/\text{mo}}{43\ \text{shifts/mo}} + (\$3.94/\text{hr} + \$17.45/\text{hr}) \times 8\ \text{hrs/shift} = \$177.52/\text{shift}$$

Assuming ten minutes of truck time per roof, the coverage during a shift is 3,906 square meters. The hourly average is 488. The cost per square meter is:

$$\frac{\$177.52/\text{shift}}{3906\ \text{m}^2/\text{shift}} = \$0.05/\text{m}^2$$

Labor comprises 79 percent of the cost of this suboperation. The costs of operation and ownership of the pickup truck make up the remaining 21 percent.

The foregoing information is compiled in Table A.3.7.1. It is clear that chemicals comprise a major part of the overall cost. One implication of this is that crude bulk application techniques, such as hosing the roof with strippable coating from the ground, are probably not cost effective. While there would be savings in per-unit labor costs due to the faster rate of application, such a method would likely result in a significant increase in the overall amount of chemical solution required since a larger portion of it would miss its target. Also, the inability to control thickness as accurately would probably necessitate a higher average volume of coating solution per unit area to assure that minimum thickness requirements were met.

The various steps comprising this operation were combined such that the rate of each was equal to the most costly. Here the most costly step is application with a rate of 81 square meters per hour. Removal would require

TABLE A.3.7.1. Summary of Cost and Productivity Data for Decontamination of Roofs Using Strippable Coating

Item	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
Chemicals	---	1.77	---	---	1.77
Application	81	0.99	0.43	0.56	---
Removal	41	0.45	0.43	0.02	---
Pickup	488	0.05	0.04	0.01	---
Total	81	3.26	0.91	0.58	1.77

nearly two (81/41 = 1.98) removal crews per application crew. Pickup would require only 81/488 = 0.166 crew per application crew.

A.3.8 Removal and Replacement

The most effective technique for removing radioactive contaminants on roofs is, of course, to remove the whole roof and replace the roof surface with a new one. However, removal should be preceded by fixing the contamination to the roof to prevent roof removal activities from inadvertently spreading radioactive particulates on surrounding pavement and lawns (see Section A.3.6).

The costs of the actual removal and replacement were taken from Means Building Construction Cost Data, 1982. In addition, a source at the American Institute of Architects in Washington, D.C., referred to Means to get estimates for roof removal and replacement. This source lists the costs of removal for just one type of roof material, even though costs for installation of several roof types were given. For this reason the cost data reported here refer to five-ply, built-up tar and gravel construction. The major cost difference between this material and others is due to materials. Some other roof types, such as asphalt strip shingles, are generally less expensive, while cedar shingle roofs cost about 50 percent more to install than five-ply, built-up roofs.

The cost for removal is listed as $50 per 100 square feet of roof. Labor comprises all of the cost, the crew consisting of one foreman and four building laborers. Means gives the rate as 1600 square feet per day, or 200 square feet per hour. This is equivalent to 16 square meters per hour, as shown in these calculations:

$$1600 \text{ ft}^2\text{/day} \times \frac{7}{8} \text{ adj} \times \frac{1}{8 \text{ hrs/day}} \times 0.0929 \text{ m}^2/\text{ft}^2 = 16 \text{ m}^2\text{/hr}$$

At 200 square feet per hour and $50 per 100 square feet, the hourly cost is $100. The cost per square meter is then found by dividing the hourly cost by the hourly coverage.

Again following Means, roof replacement requires a crew of one roofing foreman with an hourly billing cost of $27.25, four roofers at $24.25, and two roofer helpers at $18.30. The total hourly labor cost is $160.85. In addition, miscellaneous equipment comes to $10.18 per hour.

The total hourly cost is equal to the hourly rate (300 square feet) times the cost per square foot ($1.10): $330 per hour. Subtracting the labor and equipment costs from the total cost gives the hourly material cost at $158.97. Since the material cost is not subject to any productivity adjustment, it can be converted directly to a cost per square meter in the following manner:

$$\frac{\$158.97/\text{hr}}{300\ \text{ft}^2/\text{hr} \times 0.0929\ \text{m}^2/\text{ft}^2} = \$5.70/\text{m}^2$$

The adjusted production rate is

$$300\ \text{ft}^2/\text{hr} \times 0.0929\ \text{m}^2/\text{ft}^2 \times 7/8\ \text{adj} = 24\ \text{m}^2/\text{hr}$$

Dividing the hourly labor and equipment costs by the adjusted hourly coverage yields the labor cost per square meter ($6.70) and the equipment cost per square meter ($0.43). The total cost per square meter ($12.83) is found by adding the costs for the three input categories.

Table A.3.8.1 summarizes the results of these calculations and shows the total cost for removal and replacement. As previously, the more costly procedure determines the overall rate. Therefore, 24/16 = 1.5 roof removal crews for every roof replacement crew would be required to maintain the rate of 24 square meters per hour.

TABLE A.3.8.1. Summary of Roof Removal and Replacement Cost Data

Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
Roof Removal	16	6.25	6.25	--	--
Roof Replacement	24	12.83	6.70	0.43	5.70
Total	24	19.08	12.95	0.43	5.70

A.4 LAWNS

Lawns present particular difficulties for decontamination, largely as a result of the surface texture. There are three general ways to remove radiation from lawns. The first is to lift the material out of the lawn by vacuuming or close mowing. The second is to drive the contaminants down below the surface by watering or using a chemical leaching agent. The third is to remove the radioactive particles by removing the whole lawn and replacing it with a new lawn. These approaches are discussed below.

A.4.1 Vacuuming

There are a variety of ways in which lawns could be vacuumed. These include using standard home vacuums, using portable vacuums which can be strapped on one's back, using the large push-type vacuums which are often used for parking lot cleanup, using standard mobile vacuumized street sweepers, or using the very high-powered, truck-mounted vacuums described in Section A.3.1. Comparative decontamination efficiency data are not available to guide the choice of equipment. However, from the information available, it would seem that the Power-Master type truck-mounted vacuum would be too powerful for this job, while home vacuums and back-carried vacuums are too small and lack sufficient power for this sort of work. Because of capacity, power, and mobility, we assumed that vacuumized street sweepers, using existing hose intakes fitted with several feet of hose and an intake nozzle, would be the best option for this operation.

Referring to the vacuumized street sweeping data presented in Table A.1.1.9, we can calculate the cost per hour of operating this equipment by multiplying the cost per square meter by the number of square meters per hour. Doing this gives an hourly labor cost of about $18.00 for labor and $19 for equipment for a total of $37.00 per hour. This operation would require an extra worker per truck which is estimated at $24.95 per hour, the Means billing cost for a medium equipment operator. This raises the total hourly labor cost to $43.00. Additional equipment including hoses and fittings should add about $1.00 per hour to equipment charges, raising total equipment charges to $20.00 per hour. The total hourly cost is, then, $63.00 per hour.

We assume an average of 4000 square feet of lawn per house and a productivity rate of 4000 square feet of lawn vacuumed per hour. Adjusting this figure for one hour in eight being lost to non-productive radiation-control measures and lower productivity brings the average hourly coverage to 3500 square feet, or 326 square meters. Dividing this into the cost per hour yields $0.19 per square meter. The inputs' respective shares of total cost are $0.13 per square meter for labor and $0.06 per square meter for non-labor inputs. Since vacuuming lawns involves less vehicle movement than vacuuming streets, fuel costs may be somewhat lower than in street sweeping operations.

A.4.2 Water

Under some conditions, driving radiation into the soil may be an acceptable method of mitigating the radiation hazard. One way this can be accomplished is by watering the lawn. This strategy will be more attractive when there is no important underground water source which might be contaminated and when it is unlikely that the radioactive material will travel a significant distance through the soil.

The simplest and most economical way to accomplish this is for a worker to move from house to house, turning on existing sprinklers. For houses without a sprinkler system, the worker would set up hoses with ordinary lawn sprinklers attached. Any necessary watering equipment could be dropped from a large pickup or stakebed truck at various intervals along streets. After this initial equipment distribution, the hoses and so forth would probably be most efficiently moved without any motor vehicles. After setting up the water sprinkling equipment on one lawn, the water would be left running while the person moved to the next lawn. This would continue until enough time had passed so that a sufficient amount of water had been applied to the first lawn. The person would return to that lawn, shut off the water, and move any equipment to the next unwatered lawn.

For an operation such as this, there is no information based on experience. Unit cost and rate estimates are based on assumption. The hourly labor cost used is $17.45, the billing cost for common building laborers as reported in Means' Building Construction Cost Data 1981. To this is added $1.50 per hour for equipment. For a lawn of 4000 square feet, we estimate 15 minutes of labor time. This is an average, considering that for some lawns all that will be necessary would be to turn the existing sprinkler system on and off. For other lawns it will be necessary to bring sprinkler equipment, set it up, turn it on, and remove it after turning it off. Using this estimate, we have a cost per shift of:

$$8 \text{ hr/shft} \times (17.45/\text{hr} + 1.50/\text{hr}) = \$151.60/\text{shift}$$

Since there will be only seven productive hours during the eight shift hours, total coverage during a shift will be seven times the average hourly coverage of 16,000 square feet. This works out to 10,416 square meters per shift, or 1302 square meters per shift hour. The cost per unit area is

$$\frac{\$151.60/\text{shift}}{10{,}416 \text{ m}^2/\text{shift}} = \$0.014/\text{m}^2$$

This method is obviously very labor intensive. Labor comprises 92 percent of the cost ($0.013 per square meter).

A.4.3 Leaching

The action of moving the contaminants down into the soil with water can be greatly accelerated by the use of any of a number of chemical leaching agents such as ferric chloride ($FeCl_3$), EDTA (ethylenidiaminetetraacetic acid), or calcium chloride. These have the ability to solubilize contamination particles so that they are more readily carried down into the soil.

The most efficient way to handle treatment of lawns with water and leaching agents such as ferric chloride seems to be to apply a concentrated chemical solution to the lawns from a tanker truck equipped for spraying. This would be followed with a water treatment as described in the previous section (A.4.2). Several sources reported effectiveness data for 0.3-inch application of water with ferric chloride. The original study to which these sources refer used a solution of one-percent ferric chloride by weight (Dick and Balcer 1967). Percentages by weight are about equal to percentage by volume for this material. Presumably precise control of the mixture is not extremely important. The amount of leaching agent used would be determined primarily by the type of soil. Another consideration is whether it is desirable to attempt to limit the depth to which the contaminant is moved.

Ferric chloride is sold in powder form, but more frequently it is sold in a 40-percent aqueous solution. To apply enough of this solution so that there would be sufficient ferric chloride for a one-percent solution of 0.3-inch total coverage, one gallon of the 40-percent solution should be applied to every 21 square feet. This was calculated in the following way:

$$\frac{231 \text{ in}^3/\text{gal} \times 0.40 \text{ fraction } FeCl_3}{0.01 \text{ fraction } FeCl_3 \text{ desired} \times 0.3 \text{ in coverage}}$$

$$= \frac{92.4 \text{ in}^3 \; FeCl_3/\text{gal}}{0.003 \text{ in } FeCl_3 \text{ coverage desired}}$$

$$= 30{,}800 \text{ in}^2 \text{ covered } 0.003 \text{ in deep with } FeCl_3/\text{gal}$$

$$\frac{30{,}800 \text{ in}^2 \text{ covered/gal}}{144 \text{ in}^2/\text{ft}^2} = 213.9 \text{ ft}^2 \text{ covered/gal}$$

$$213.9 \text{ ft}^2/\text{gal} \times 0.093 \text{ m}^2/\text{ft}^2 = 19 \text{ m}^2 \text{ covered/gal}$$

Various sellers of ferric chloride were contacted. The prices for a ton of ferric chloride on a 100 percent basis for large volume shipments are shown in Table A.4.3.1. Prices differ largely because of volume, packaging, and shipping factors. On the basis of these figures, we used a price of $200 per

TABLE A.4.3.1. Prices of Ferric Chloride by Various Suppliers for Large Volume Shipments

Supplier	Price (1982 $/ton)
Conservation Chemical	200
DuPont, Chemicals, Dyes & Pigments Dept.	176
C.P. Hall	260
Chemwest	200

ton of ferric chloride. This is equivalent to $0.10 per pound. Further, Conservation Chemical and C.P. Hall reported that a 55 gallon drum of 40 percent solution weighs 600 lbs. Thus, a gallon weighs about 11 pounds which means there are about 4.4 pounds of material per gallon; therefore, the cost is about $0.44 per gallon.

Including an allowance for shipping and so forth brings the cost to about $0.50 per gallon. The cost of ferric chloride per square meter is:

$$\frac{\$0.50/gal}{19m^2/gal} = \$0.0263/m^2$$

A hydroseeder, as described by a source with the Washington State Department of Transportation, would provide an effective means of applying the concentrated leaching agent solution. This machinery can easily spray surfaces within a radius of 100 feet. The reported average coverage rate of this equipment is in excess of an acre per hour at 0.4 gallons per square yard. This is equivalent to an average pumping rate of 32 gallons per minute. These figures include time for refilling. It is possible that metal surfaces on the hydroseeder may have to be coated to prevent corrosive action of the leaching agent.

The Washington State Department of Transportation reported that the hydroseeder entails a labor cost of $60 per hour for two workers plus $135 per hour for the equipment. The application rate of one gallon for 19 square meters is probably too thin to be done with much uniformity of coverage. Therefore, we assume that the solution is partially diluted before applying. If the ferric chloride is diluted, say, four parts water to one part of the solution as purchased, then one gallon of this mixture should be applied over an area of about 3.8 square meters. The pump rate of 32 gallons per minute for the hydroseeder multiplied by the coverage of 3.8 square meters per gallon gives an output of 122 square meters per minute. Coverage per shift-hour would be

$$122\ m^2/min \times 60\ min/hr \times 7/8\ adj = 6400\ m^2/hr$$

Dividing this into the hourly costs gives $0.009 per square meter for labor, $0.021 for equipment. The total cost of operating the hydroseeder apart from the leaching agent is $0.03 per square meter.

The costs of applying the water are explained in the previous section.

Table A.4.3.2 summarizes the cost of leaching. Combining the different procedures so that the overall rate equals the rate of the most costly step requires that 4.92 watering crews be used for every application crew.

TABLE A.4.3.2. Summary of Leaching Cost and Productivity Data

Item	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Materials
Ferric Chloride	--	0.026	--	--	0.026
Application of Chemicals	6400	0.030	0.009	0.021	--
Watering	1302	0.014	0.013	0.001	--
Total	6400	0.07	0.022	0.022	0.026

A.4.4 Close Mowing

Close mowing of contaminated lawns is another method of reducing the radiation hazard from that surface. Because the total lawn surface will be broken down into numerous small, odd-sized parts, and because some lawns will have only limited access, large mowers would be too cumbersome for efficient use. Smaller riding mowers seem to be the most attractive option. Besides mowing, the workers must also see that lawn cuttings are carefully bagged for later removal. Mowers with a vertical axis cutting blade would be used since they would pick up particles with a vacuum action.

Three sources supplied cost and rate estimates for this operation. Since the equipment specifications did not change much from source to source, the major areas of difference were in wage rates and productivity rates. An allocation of about $2.00 per hour appears to be adequate to cover the costs of the mower, maintenance, and fuel. We estimate that 15 minutes of time for labor and a pickup truck is sufficient for pickup and disposal of bagged clippings.

According to Means' Building Construction Cost Data 1982, the monthly rent for a pickup truck is $275, and the hourly operating cost is $4.24. With 336 working hours per month, the hourly cost for the truck is:

$$\frac{\$275/\text{mo}}{336\ \text{hrs/mo}} + \$4.24/\text{hr} = \$5.23/\text{hr}$$

Using Means' billing rate cost for a common labor of $17.45, the total hourly cost for the pickup of lawn cuttings is

$$\$5.23 + \$17.45 = \$22.68/\text{hr}$$

Based on the estimate of 15 minutes pickup time per 4,000 square foot lawn, total coverage during the seven working hours of an eight hour shift would be 112,000 square feet or 10,416 square meters. Dividing this figure by eight hours per shift gives the average coverage per shift hour as 1,302 square meters. The cost per square meter can be calculated by dividing the cost per hour by the coverage per hour:

$$\frac{\$22.68/\text{hr}}{1302\ \text{m}^2/\text{hr}} = \$0.017/\text{m}^2$$

The Administrative Services Department of the Spokane Community College in Spokane, Washington said that for large, flat, unobstructed areas a large mower such as a Toro Lawn Master with a 4.5 foot mowing width can mow one acre in 15 minutes. However, using a small riding mower for mowing the front and back lawns of a standard 50 foot width lot, this source estimates that 45 minutes are required. To this should be added time for bagging the clippings. This translates into about one hour for 4,000 square feet, or 372 square meters. With an hour per shift lost to special protective measures necessitated by the radioactivity, the average hourly production would be 7/8 of this amount--326 square meters per hour.

Using Means' common laborer billing rate of \$17.45 per hour for the labor cost, the total hourly cost would be \$19.45 when the equipment cost is included. The cost per square meter is:

$$\frac{\$19.45/\text{hr}}{326\text{m}^2/\text{hr}} = \$0.060/\text{m}^2$$

Labor would account for:

$$\frac{\$17.45}{326\ \text{m}^2/\text{hr}} = \$0.054/\text{m}^2$$

American Maintenance Systems in Seattle, Washington, provided a similar estimate - 45 minutes to an hour to mow 4,500 square feet. Adding the time for bagging, this comes to an hour and fifteen minutes. Adjusting for an average of one hour per shift lost due to the special conditions of working in a contaminated environment, gives

$$\frac{4500\ \text{ft}^2}{1.25\ \text{hr}} \times 0.093\ \text{m}^2/\text{ft}^2 \times 7/8 = 293\ \text{m}^2/\text{hr}$$

Again, using \$17.45 per hour for labor and \$2.00 per hour for capital and dividing by the hourly production yields a cost per square meter of \$0.0664.

The Craft and Operation Services Department of Battelle Pacific Northwest Laboratories in Richland, Washington estimated 10 to 12 hours for 20,000 square feet. This is much slower than the other estimates in part because specific consideration was given to time necessary for the bagging of cuttings and for the slower mowing rate necessitated by cutting the grass as close to the ground as possible. Using a time of 11 hours for 20,000 square feet, the production during an average hour of mowing would be

$$\frac{20{,}000\ \text{ft}^2}{11\ \text{hrs}} \times 0.093\text{m}^2/\text{ft}^2 = 169\text{m}^2/\text{hr}$$

Adjusting this figure for an hour lost per shift for reasons connected with working in a contaminated area, the average hourly production becomes

$$169\text{m}^2/\text{hr} \times \frac{7}{8} = 148\text{m}^2/\text{hr}$$

With a labor cost of \$20.00 per hour plus \$2.00 per hour for equipment, the average cost per square meter is

$$\frac{\$22.00/\text{hr}}{148\text{m}^2/\text{hr}} = \$0.1486/\text{m}^2$$

Table A.4.4.1 presents the foregoing data. It is clear that the cost estimate for mowing from Battelle is much higher than the estimates from the other two sources. The reason for this is the explicit consideration given by the source at Battelle for the special actions which must be taken in this case: mowing as close to the ground as possible and careful bagging of the cuttings. Because of these explicit considerations, the representative figures for this procedure are taken as very close to the Battelle figures.

The total cost for the whole operation is the sum of the mowing cost plus the removal cost - \$0.147 per square meter. The overall rate is geared to mowing, the more costly step. This means that 150 ÷ 1302 = 0.115 pickup crews would be required for every mowing crew.

TABLE A.4.4.1. Summary of Cost and Productivity Data for Close Mowing of Lawns

Item and Source	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment
Mowing				
Spokane Comm. Coll.	326	0.060	0.054	0.006
Amer. Maint. Sys.	293	0.066	0.059	0.007
Battelle PNL	148	0.149	0.136	0.013
Pickup				
Means	1302	0.017	0.013	0.004
Representative				
Mowing	150	0.130	0.116	0.014
Pickup	1302	0.017	0.013	0.004
Total	150	0.147	0.129	0.018

A.4.5 Fixative

A sticky, penetrating type of fixative might be the most appropriate for use on lawns, though hydrophillic and solid membrane types could also be used. According to the Washington State Department of Transportation, the first step of coating the lawn surfaces with a fixative could be done with a hydroseeder. This is a tanker truck equipped to spray liquids of varying viscosity to surfaces within a 100 foot radius. With a coverage of, say, 0.4 gallons per square yard, this equipment can deliver liquids at a rate sufficient to cover an acre per hour. This implies a pumping capacity of 32 gallons per minute. The hydroseeder requires two workers - a driver and someone to operate the spraying mechanism. The reported cost of operating the hydroseeder is \$60 per hour for the two workers plus \$135 for the equipment. The equipment charge includes allowance for capital, depreciation, maintenance, fuel, and so forth. These costs work out to a total of \$1560 per shift.

The hydroseeder's coverage rate of an acre per hour is equivalent to 4,051 square meters per productive hour. During the seven productive hours of a shift, the total production would be 28,357 square meters. Thus, the unit cost would be

$$\frac{\$1560/\text{shift}}{28{,}357\text{m}^2/\text{shift}} = 0.055/\text{m}^2$$

Labor's share of the cost is

$$\frac{\$60/\text{hr} \times 8 \text{ hrs}}{28{,}357 \text{ m}^2/\text{day}} = \$0.017/\text{m}^2$$

or $0.017 per square meter. Equipment accounts for the remaining $0.038 per square meter. The average production per shift-hour is

$$\frac{28{,}357\text{m}^2/\text{shift}}{8 \text{ hrs/shift}} = 3{,}545\text{m}^2/\text{hr}.$$

Referring to Section A.7.1, the cost of a fixative appropriate for use on lawns covers a broad range. Here we assume that a fixative like road oil would be used with a unit cost of $0.31 per square meter. This brings the total cost of fixative and application to $0.365. Table A.4.5.1 summarizes the cost and

TABLE A.4.5.1. Summary of Cost and Productivity Data for Applying Fixative to Lawns

Item	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Fixative	--	0.310	--	--	0.310
Application	3545	0.055	0.017	0.038	--
Total	3545	0.365	0.017	0.038	0.310

productivity data for the application of a fixative to lawns. It is clear that selection of a lower cost fixative would have a significant impact on the total cost.

A.4.6 Removal and Replacement

A relatively effective but costly method of reducing radiation contamination in lawns is to take the direct approach of removing the lawn and replacing it with new sod. To be sure that the radioactive matter is fixed to the lawn to be removed, removal should be preceded by application of a fixative. That step is not included in removal and replacement as described here.

Sod removal and replacement are normally done by the same business and, therefore, the cost is frequently given for the combined procedure. A source at the American Institute of Architects provided a cost estimate of $4.12 per square yard for removal and replacement of sod on flat terrain and \$4.53 on a slope. These are figures for the East Coast which should be higher than the national average. Apparently, these data were taken from a Means construction cost publication. Using the average of the figures for level and sloped surface, the cost can be converted to a cost per square meter basis. The following shows this calculation and adjusts for one hour per shift with no production:

$$\frac{\$4.12/yd^2 + \$4.53/yd^2}{2} \times 0.8361\ m^2yd^2 \times 8/7 = \$4.13/m^2$$

C&M Landscaping of Richland, Washington, charges \$0.50 per square foot for lawn removal and replacement. This can be converted to a cost per shift-hour in the following way:

$$\frac{\$0.50/ft^2}{0.093m^2/ft^2} \times 8/7 = \$6.14/m^2$$

Means' Building Construction Cost Data 1982 (p. 56) indicates that the crew for sodding requires one outside foreman (\$22.25 per hour billing cost), four building laborers (\$19.40) and one light-equipment operator (\$23.70). The total hourly labor cost is \$123.55. Necessary earthwork equipment has an hourly cost of \$19.86. The total hourly cost on level ground is

$$470\ yd^2/day \div 8\ hrs/day \times \$3.98/yd^2 = \$233.83$$

Subtracting the hourly labor and equipment costs gives the hourly material cost, which can be converted to a dollars-per-square-meter basis with the following calculations:

$$\$(233.83 - (123.55 + 19.86)) = \$90.42/hr \text{ for material}$$

$$\frac{\$90.42/hr}{58.75\ yd^2/hr \times 0.836\ m^2/yd^2} = \$1.84/m^2$$

The rate given for sodding on level ground is 470 square yards per day, and the rate for slopes is 405 square yards per day. We base our calculations on the average of these two rates - 438 square yards per day. Converting to square meters and accounting for one hour per day lost to radiation control measures, we have:

$$438\ yd^2/day \div 8\ hrs/day \times 7/8\ adj \times 0.836\ m^2/yd^2 = 40\ m^2/hr$$

Dividing the hourly coverage rate into labor and equipment costs gives those costs on a dollars-per-square-meter basis:

$$\text{Labor:} \quad \frac{\$123.55/hr}{40\ m^2/hr} = \$3.09/m^2$$

$$\text{Equipment: } \frac{\$19.86/\text{hr}}{40\ \text{m}^2/\text{hr}} = \$0.50/\text{m}^2$$

Adding the labor, equipment, and material cost gives the total cost as $5.43 per square meter.

The costs given here are different from those given by the American Institute of Architects (AIA), despite the fact that the AIA stated that its source was a Means publication. It appears that the AIA may have used an earlier edition.

Partial information was also supplied by Elite Sod Farm, Richland, Washington. The cost of laying new sod near this business was $0.16 to $0.22 per square foot. This does not include removal of existing lawn. These costs are equivalent to $1.72 to $2.36 per square meter without adjustment for the special radiation measures affecting costs and production rates. Averaging these two amounts together and adjusting for an hour per shift lost due to special conditions imposed by radiation, we get $2.33 per square meter.

Table A.4.6.1 presents the foregoing information. The various costs for removing and installing sod, while not in perfect agreement, seem to be mutually consistent. The representative cost was taken as the Means data.

TABLE A.4.6.1. Summary of Cost and Productivity Data for Removing and Replacing Lawns

Source and Item	Rate ($/m^2)	Cost (1982 $/m^2) Total	Labor	Equipment	Material
Amer. Inst of Archs					
Remove and resod	--	4.13	--	--	--
C & M Landscaping					
Remove and resod	--	6.14	--	--	--
Means					
Remove and resod	40	5.43	3.09	0.50	1.84
Elite Sod Farm					
Resod Only	--	2.33	--	--	--
Representative	40	5.43	3.09	0.50	1.84

A.5 AGRICULTURAL FIELDS

Agricultural fields include lands planted and harvested annually or more often. Crops are primarily grains and vegetables. The cost of most operations would be affected by the time in the crop growing cycle in which the fields were contaminated and in which the decontamination operations were undertaken.

A.5.1 Low-Pressure Water

There are several ways in which water could be applied to a field. The simplest would be to use an existing irrigation system, should one be present. However, since many fields--especially those for raising grain--are not irrigated, the cost of applying water was estimated for application using a tank truck with spreader or spray capability. Data used included that for applying water to paved surfaces (see Section A.1.2). This was adjusted to account for the slower rate of application resulting from driving on soft dirt rather than pavement, and also for a longer time to refill the tank. The slower vehicle speed has a relatively small effect on cost, however, since vehicle speed must be slow in either case in order to apply sufficient water. The most important factor affecting cost is the time required to refill the tankers. Where water sources are not available nearby, the cost will be much greater.

In Section A.1.3, equipment for applying high-pressure water to pavement was described. This consisted of a tank truck equipped with a pump and a laterally mounted ten-foot spray bar. Similar equipment could be used for applying water to agricultural fields, though it would not be necessary to apply the water at high pressure. Another alternative is to use a water distributor truck as is used in road construction. These sorts of equipment configurations should not have significantly different costs.

Here, following the discussion in A.1.3, we use an hourly labor cost of \$19.75 and an hourly equipment cost of \$27.37. This gives a total cost of \$47.12 per hour.

The rate of surface coverage is crucial in estimating the cost per unit area. For applying water to pavement with this equipment, a vehicle speed of one mile per hour while spraying was assumed. There would seem to be no real problem in maintaining the same average vehicle speed on agricultural fields. The difference in overall rates will occur as a result of different refill times. In irrigated farm areas, refill times may be no longer than for roads. However, because in dryland areas water sources may be some distance away from the treatment area, we assume that on average the application rate will be 80 percent of what it is for paved roads.

The rate is, therefore:

$$2686 \text{ m}^2/\text{hr} \times 0.80 = 2149 \text{ m}^2/\text{hr}$$

Dividing the hourly production rate into the hourly cost figures yields \$0.0092 per square meter for labor, \$0.0127 per square meter for equipment, and \$0.0219 per square meter total.

A.5.2 Fixative

Fixatives and their characteristics are described in Section A.7.1. No single fixative is clearly superior for all instances in which a fixative might be applied to agricultural fields. Here we use Coherex as the fixative. This has a cost of \$0.19 per square meter when applied using a 1:5 mixture with water.

The equipment to apply the fixative is basically the same as that described in Section A.1.3 for applying high-pressure water to pavement. Here, high pressure is neither necessary nor desired. Further, it is not necessary to apply as much volume of material per square meter as with the water treatment. Therefore, the spray truck can move forward at a somewhat faster rate. In this case a vehicle speed of 1.36 miles per hour is appropriate when the pump rate is 100 gallons per minute and the spray width is ten feet.

A 5000-gallon capacity tank truck will be emptied in 50 minutes with a 100 gallon per minute spray rate. The assumed refill time for water in Section A.1.3 was 30 minutes. Here we raise the assumed refill time to 50 minutes to account for mixing of the fixative with water and the likelihood of a greater travel distance to the refill location. Alternatively, the spray truck could be supplied by "feeder" or "nurse" trucks, though it is not clear that this would result in any cost savings.

Since spray and refill times are equal, 3.5 of seven hours will be spent spraying. Therefore, 4.2 loads will be applied per shift. Coverage per shift-hour is

$$3.5 \text{ hrs} \times 1.36 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.0929 \text{ m}^2/\text{ft}^2$$
$$\div\ 8 \text{ hrs/shift} = 2922 \text{ m}^2/\text{hr}$$

This rate is divided into the hourly cost figures as shown:

$$\text{Labor:} \quad \frac{\$19.75/\text{hr}}{2922} = \$.0068/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$27.37/\text{hr}}{2922} = \$0.0094/\text{m}^2$$

Adding the material cost to these two figures yields the total cost per square meter: \$0.2061.

A.5.3 Leach

In some circumstances it may be acceptable to leach the contaminant into the soil. This would not be the case where doing so would pose a threat of contamination to underground water supplies. Another consideration is root uptake, which could cause exposure via the food ingestion pathway. This suggests that an acceptable strategy in agricultural fields may be to leach the contaminant to a short distance below the root depth but no further. Leaching agents that either break down themselves or start to release the contaminant and pick up and act on other chemicals in the soil could be used in this strategy.

EDTA (ethylenidiaminetetraacetic acid) is one candidate for leaching. According to a technical services representative at Dow Chemical Co., it is used frequently for decontaminating surfaces in nuclear reactors. It is particularly effective for removing radioactive scale. EDTA is a chelating agent, meaning that it will bind with metal ions and keep them soluble. Since EDTA is oxidizable with light or oxygen, it will break down and release the ions to which it had been bound. Therefore, a very careful application of EDTA could be used to transport the contamination from the surface to a desired depth. Besides the rate of oxidation and bacteriological breakdown of EDTA, another factor is the chemical composition of the soil. EDTA will chelate with other metal ions (notably calcium) present in the soil in addition to the radioactive ones. In general, the amount of preexisting calcium in the soil will determine the amount of EDTA to apply.

Since EDTA is not very water soluble, the sodium or ammonium salt of EDTA is the form in which it is usually sold. Dow markets an EDTA sodium salt under the name of Versene 100. The bulk price is 36.5 cents per pound for this 39 percent active solution. The Dow technical representative suggested that dilution of about twenty parts water to one part EDTA solution, making about a two percent solution, would be a reasonable formulation of an EDTA leaching solution. This would handle about 1,000-2,000 parts per million of metal ions in the soil.

Another leaching agent that might be used is ferric chloride ($FeCl_3$). This is described in Section A.4.3. In that section the cost of applying a one-percent solution was calculated. The cost of the ferric chloride was \$0.0263 per square meter. Because of this lower cost, leaching here is assumed to be done with ferric chloride. Another reason for basing these computations on ferric chloride is that there is some test data on the effectiveness of this material used for radiation decontamination.

The same equipment and personnel used to apply water to agricultural fields (see Section A.5.1) would be used for leaching. However, to apply the necessary greater amount of water, a slower vehicle speed would be called for. Experimental data were produced based on an application of 0.30 inches of the water-ferric chloride solution (Dick and Baker 1967). This volume requires a vehicle speed of 0.6 miles per hour. As with fixative application (see Section A.5.2), the application tank truck would be spraying half the time and re-filling half the time. The average coverage per shift-hour would be 1814 square meters. Dividing this result into the hourly labor and equipment costs gives the costs of these inputs on a square-meter basis.

$$\text{Labor:} \quad \frac{\$19.75/\text{hr}}{1814\ \text{m}^2/\text{hr}} = \$0.0109/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$27.37/\text{hr}}{1814\ \text{m}^2/\text{hr}} = \$0.0151/\text{m}^2$$

Summing the labor, equipment, and material costs gives the total cost per square meter: \$0.052.

A leaching agent would normally be applied with a water tank truck equipped with a spray boom to achieve fairly even application. Following application of the leaching agent, water would be applied either by truck or via an irrigation system.

A.5.4 Clear

Deciding whether it is necessary to clear an agricultural field of vegetation depends principally on the amount of vegetation and the operation(s) to follow. For example, clearing a wheat field prior to scraping would probably not be necessary. On the other hand, clearing a corn field on which the crop had nearly reached full growth probably would be a requirement before application of some other treatment such as leaching or scraping.

Besides facilitating subsequent operations, clearing will also remove much of the contamination residing on the vegetation. The efficiency of this procedure would be increased by a prior, possibly aerial, application of a fixative.

In most cases, clearing of agricultural fields would be accomplished using standard harvesting equipment. Since the likelihood that the crop could be cleared increases with the bulk of the crop, it was assumed that corn was the crop to be cleared.

The publication Custom Rates for Farm Operations (May 1979) listed the cost of combining corn at $14-15 per acre plus $0.20 per hundredweight. However, combining is a more involved procedure and probably uses more costly equipment than is necessary. A source in the U.S. Department of Agriculture suggests that a swather would be the best alternative for clearing. Besides removing the plants, it also bundles or bales the crop. The cost per acre was broken down as follows:

Baler twine	$10.80
Machinery and fuel	21.42
Repair	25.89
Labor	33.22
Interest	2.95
Total	$94.28

For our purposes we can group all non-labor costs ($61.06) under equipment.

The rate given was 6.52 hours per acre. This converts to

$$\frac{4046.7\ m^2/\text{acre}}{6.52\ \text{hrs/acre}} \times \frac{7}{8}\ \text{adj} = 543\ m^2/\text{hr}$$

The hourly costs of the inputs can be calculated by dividing the costs per acre by the number of acres per hour. Dividing again by the number of square meters per hour gives the cost per square meter.

Total: $\$94.28/ac \div 6.52\ hrs/ac \div 543\ m^2/hr = \$0.027/m^2$

Labor: $\$33.22/ac \div 6.52\ hrs/ac \div 543\ m^2/hr = \$0.009/m^2$

Equipment: $\$61.06/ac \div 6.52\ hrs/ac \div 543\ m^2/hr = \$0.017/m^2$

There is an additional cost for hauling away the cleared material. Since hauling is necessary in connection with several operations, hauling costs are discussed separately elsewhere in the Appendix. However, it is necessary to estimate the volume of material to be hauled. For clearing of agricultural fields, we estimate about 0.10 cubic meters of material per square meter of surface treated.

A.5.5 <u>Scrape</u>

Scraping involves the removal of the top surface of soil. In general, the objective is to remove a thin but as complete a layer as possible. This goal is made difficult by surface irregularities. Further, earth moving equipment has limited precision with respect to removing a thin layer of soil. In consequence, according to several sources, average removal depth will be about four to six inches.

Since earth-moving operations are fairly common, there are a number of sources and considerable information available. Published sources include annual editions of Means' <u>Building Construction Cost Data</u>, Engelsman's <u>Heavy Construction Cost File</u>, and McGraw-Hill's <u>Dodge Guide</u>. Further, industry sources--Doolittle Construction Company, World Excavating and T.E. Knudson, construction consultant--were also contacted for this report. Additional information was also obtained from the Reynolds Electrical and Engineering Co., Inc., Joseph M. Hans, Jr., and other reports on decontamination procedures. These reports included "Radiological Dose Assessment and the Application and Effectiveness of Protective Actions for Major Property Types Contaminated by a Low-Level Radionuclide Deposition" by Science Applications, Inc., and "Estimate of Potential Costs of Hypothetical Contaminating Events, Subject to 'Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment'" by Battelle-Northwest.

Since scraping is a relatively common operation, there are a variety of techniques and equipment available. For example, the basic scraping equipment could be either a crawler tractor, a bottom-dump scraper, or a grader. While all these seem to be reasonably effective, information from sources experienced in scraping as a decontamination procedure indicated a preference for the grader and front-end loader. The grader scrapes earth into windrows and a front-end loader loads the windrows into dump trucks. This is the principal technique used by the Reynolds Electrical and Engineering Co., Inc., at the Nevada Test Site where they have been engaged in scraping and removing soil contaminated in weapons tests. This source reported that where soil is particularly hard they use a crawler tractor instead. The procedure in this case is for the tractor to drive over the soil first with rear-mounted shallow ripper shanks in a lowered position. After scarifying the soil, the tractor raises the shanks, backs up, lowers the front scoop and proceeds to push the earth into rows or piles. These piles are later picked up by a front-end wheel loader and loaded into a dump truck.

Joseph M. Hans, Jr., of the U.S. Environmental Protection Agency, was involved with the decontamination of a uranium mill site. In this work he gained a familiarity with the effectiveness of earth-moving equipment. He found that common problems include equipment actually driving the contamination below the surface and soil spillage. He reports that equipment needs vary from site to site and that push bottom-dump scrapers were inefficient because they removed too much soil.

In reviewing scraping practices as used in decontamination projects and as used in ordinary earth-moving work, it appears that a grader working with one or more front-end loaders in the manner described above constitutes a fairly effective and efficient technique for soil removal.

Those doing decontamination work found that, in addition to the actual scraping, periodic wetting of the soil prevented dust. Application of water was done either with a water wagon or a hydroseeder. Using a hydroseeder to spray water may permit wetting the contaminated soil from a decontaminated area. This reduces disturbances to the contaminated area. Occasionally a small amount of detergent is added to the water to improve wetting.

A final element in the scraping operation is the transporting of contaminated soil to a dump site. The cost of dumping will depend in large part on the distance to the dump site. Some sources envision a dump site for every square kilometer (Julin et al. 1978). At another extreme, soil would be transported to one of the few national nuclear-waste dumps. Such hauls could be over 1,000 miles. Another possibility is that a dump site would be created in or adjacent to any permanently interdicted area.

Relying on Means, an estimate of scraping costs can be developed. The basic piece of equipment is a grader. A 30,000 pound grader costs $51.34 per hour. Operating with the grader are two wheel-mounted front-end loaders, each with a 2.25 cubic yard capacity and each costing $50.79 per hour. The total equipment cost is $152.92 per hour.

The labor requirements are three medium-equipment operators at $24.95 per hour each, one building laborer at $19.40 per hour, and one foreman at $22.25 per hour. The total labor cost comes to $116.50 per hour. Adding the labor and equipment costs together, we get the total hourly cost of $269.42.

The rate is more difficult to estimate. Apparently, the limiting factor is the speed at which the front-end loaders can load the windrows into dump trucks. The front-end loaders are listed as having a 2-1/4 cubic yard capacity with a loading rate of 100 cubic yards per hour. With a scraping depth of about six inches, about five square meters are covered for every cubic yard. Therefore, each front-end loader can cover about 500 square meters per hour. The second loader brings the production rate to 1000 square meters per hour. Adjusting this for the time necessary for personnel and equipment decontamination reduces the rate to 875 square meters per hour. This figure appears to be within reason when compared with those reported by other sources. For example, Doolittle Construction estimated a rate of 146 square meters per hour. This was with a smaller crew and only one loader. Reeco indicated that their rate is about an acre a day or about 500 square meters per hour. The rate derived from McGraw-Hill's Dodge Guide was a little over 4000 square meters per hour. It should also be noted that these estimates are for scraping vacant land, which would normally take longer than scraping agricultural fields.

Dividing the hourly production rate into the hourly costs gives the cost in dollars per square meter. The total is \$0.31, labor is \$0.13 and equipment comes to \$0.18 per square meter. Total costs per square meter reported by other sources were:

Doolittle Construction	\$0.34
Science Applications (1978)	0.16
Reeco	0.24
McGraw-Hill	
Loose soil	0.26
Broken rock	0.61
Battelle (1978)	0.47
World Excavating	0.23

A.5.6 Plow

Both by mixing and turning the soil, plowing is an effective method of reducing radiation hazards from external exposure and inhalation. Since plowing is a relatively common operation for which much data has been collected, there is a considerable amount of information about plowing. Farm advisors and publications of agricultural extension services are good sources. For the present report, additional sources were contacted, including farm management consultants and academic sources.

There are various types of plowing operations, including chisel plowing, heavy discing, and mouldboard plowing. Mouldboard plowing is particularly appropriate for the purposes at hand because it turns the soil more than cutting it. This would be the most effective plowing technique to move surface-level contamination below the soil. Most plowing operations operate to depths of eight to ten inches, though some plowing is done to depths of 18 inches and 12-inch deep plowing is not uncommon. For plowing to greater depths - three feet deep and more - see the next section, A.5.7, concerning deep plowing.

The University of California, Division of Agricultural Sciences publication Custom Rates for Farm Applications gives the cost of plowing at \$10-12.50 per acre in 1978 dollars. In 1982 dollars this amounts to \$15.75 to \$17.20 per acre, using the gross national product implicit price deflator to adjust to 1982 price levels. Using the upper end of this range and adjusting for an hour per shift for radiation control measures, we find the cost per square meter as

$$\frac{\$17.20/\text{ac}}{4046.7\ \text{m}^2/\text{ac}} \times \frac{8}{7}\ \text{adj} = \$0.0049/\text{m}^2$$

The indicated rate was about 1.8 acres per hour. This implies a coverage rate of

$$1.8\ \text{ac/hr} \cdot 4046.7\ \text{m}^2/\text{ac} \cdot 7/8\ \text{adj} = 6374\ \text{m}^2/\text{hr}$$

Iowa State University Cooperative Extension supplied results from 1983 Iowa Farm Custom Rate Survey which showed that mouldboard plowing averages about $10.70 per acre (in 1982 dollars). The cost ranges from $9.00 to 12.40 per acre. At $10.70 per acre, the adjusted cost per square meter is $0.0030. The approximate breakdown of these costs is 25% for labor, 55% for equipment and 20% for fuel. These figures were confirmed by King Management Company, a farm management concern in Des Moines, Iowa. This source added information about related operations. Chisel plowing to a depth of 12 inches costs about $0.0024 per square meter, and heavy discing to a depth of 12 to 18 inches costs about $0.0022 per square meter.

From this information, we take as representative a total cost of $0.004 per square meter. This is comprised of $0.001 for labor, $0.002 for equipment, and $0.001 for fuel. The hourly rate is 5000 square meters.

A.5.7 Deep Plow

Deep plowing here refers to plowing to a depth of about 36 inches, though there are procedures for plowing any depth up to 36 inches and deeper. In addition, there are a number of different techniques and terms associated with deep plowing, including ripping, subsoil, and slip plowing. Most deep plowing operations involve pulling one, two, or three shanks through the soil with a large tractor. Agristruction, Inc. operates a rig with seven shanks, over a 16.5-foot width, that rip to a depth of 32 inches. Some operations turn 36 inches of soil using a large mouldboard plow. For hard soil it is sometimes necessary to use a second tractor pushing or pulling the first. One source (Agristruction, Inc.) uses 14-foot shanks weighing a ton each to rip very hard soil up to five feet deep.

Deep plowing is not a particularly common farm operation. One region in which deep plowing is not uncommon is the Southern San Joaquin Valley in California. In this area deep plowing is used to break up a layer of hard pan below the surface in order to facilitate root penetration. Most deep plowing is done by custom farming companies that specialize in this type of work.

Because equipment, soil conditions, procedure, and plowing depth differed from source to source, cost estimates varied considerably. The lowest was equivalent to $0.008 per square meter, while the highest figure was $0.20 per square meter. Table A.5.7.1 summarizes the data collected. The figures are adjusted for reduced productivity and time taken for personnel and equipment protection due to radiation.

TABLE A.5.7.1. Deep Plowing Cost Data Summary

Source and Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2)
Univ of Calif Coop Exten, "Costs to Estab. and Produce Walnuts"		
Shallow subsoil	--	0.0141
Univ of Calif Coop Exten, "Custom Rates for Farm Operations"		
Subsoil (36")	7588	0.0082
Rip (6')	--	0.0194
Agristruction, Inc.		
Rip soft soil (5')	5311	0.1130
Rip hard soil (5')	1328	0.1412
Can-Do Custom Farming		
Slip plow (18")	2479	0.10
Slip plow (36")	2833	0.20
Moorehead and Idell		
Slip plow (36")	4249	0.03
Battelle (1978), "Estimate of Potential Costs..."		
Plow (1 m)	--	0.06
Dave Price		
Slip plow (6')	2656	0.10
Mouldboard plow (52")	1770	0.11
Braden Farms		
Rip	6551	0.015
Valley Tractor Co.		
Plow (36")	6374	0.047
Plow (52")	3541	0.11
Valley Agricultural Consultants		
Slip plow	2479	0.022

The representative rate and cost are taken as 5000 square meters per hour and $0.06 per square meter. The labor cost is figured at $0.005 per square meter based on an hourly operator billing cost of about $25.00 per hour.

A.5.8 Clear

Clearing refers to removing the plant cover. This operation has two functions. The first is the obvious one of effecting a degree of decontamination since the removed plant cover will take with it a proportion of the radioactive particles. The second function of clearing is to facilitate the execution of subsequent operations. For agricultural fields, most crop cover is not likely to impede other operations. However, there could be cases in which this would not be the case. For example, corn at or near full growth would certainly pose an obstacle to other treatment measures.

Corn was, in fact, used as the representative crop to be cleared. For corn and for other crops, it appears that associated farm machinery offers the best possibility for the lowest-cost way to clear the crop. Clearing may therefore entail harvesting the crop. Conversation with a representative of the U.S. Department of Agriculture in Seattle, Washington indicated that for the purposes of clearing corn a swather may be the best option. This will bale the stalks to facilitate removal. The average cost per acre for this procedure is $94.28. This is broken down into $10.80 for baler twine, $21.42 for machinery and fuel, $25.89 for maintenance and repair, $2.95 for interest on equipment, and $33.22 for labor. Combining the non-labor costs under equipment, we get $61.06 per acre.

Swathing requires about 6.52 hours per acre, which is equivalent to 0.15 acres per hour. Multiplying cost per acre by this acres-per-hour figure gives the cost of swathing as $14.47 per hour. The hourly labor cost is $5.10, and the equipment cost is $9.36 per hour. Converting the acres-per-hour figure to square meters per hour can be done as follows:

$$0.15 \text{ ac/hr} \times 4046.7 \text{ m}^2\text{/ac} \times 7/8 \text{ adj} = 543 \text{ m}^2\text{/hr}$$

Dividing the hourly cost figures by this hourly production rate yields the cost of swathing on a per-square-meter basis. The total is $0.026. Labor accounts for $0.009 per square meter, and equipment $0.017.

This operation requires a farm equipment operator and a swather as the primary inputs.

A.5.9 Cover

This operation involves covering the ground with six inches of uncontaminated soil. This may be done to replace soil which has been removed as a radiation treatment measure, or the contaminated ground may be covered by the new soil. However this operation fits into a decontamination program, the soil cover will help reduce resuspension and external exposure.

The first step in this operation is the excavation of the earth that is to be spread in the treatment area. This excavation might be coupled with contaminated-material disposal. If a pit is to be dug for disposing of contaminated soil or other materials, the removed soil might be usable for covering. The excavated soil would be hauled to the decontaminated site, dumped there, and spread by a front-end loader.

Means' Building Construction Cost Data 1982 (p. 29) lists several ways to accomplish bulk excavation. The least costly is to use a large (five cubic yard capacity) wheel-mounted front-end loader. This equipment can excavate and load 1480 cubic yards per day of medium soil. Noting that each cubic yard of soil will cover six square yards six inches deep, the hourly coverage rate is

$$\frac{1480\ \text{yd}^3/\text{day}}{8\ \text{hrs/day}} \times 6\ \text{yd}^2/\text{yd}^3 \times 0.836\ \text{m}^2/\text{yd}^2 \times 7/8\ \text{adj} = 812\ \text{m}^2/\text{hr}$$

Means calls for one medium-equipment operator at $24.95 per hour billing cost and half a building laborer at $19.40 per hour as the labor input. This totals $34.65 per hour. The front-end loader costs $100.38 per hour. The total hourly cost is $135.03. Dividing these figures by the hourly production rate gives costs in terms of dollars per square meter: total, $0.166; labor, $0.043; equipment, $0.123.

The cost of hauling is handled separately since it depends on the distance.

Means (p. 32) also supplies data for estimating the cost of spreading and grading the new soil. The inputs for this step are similar to the excavation step. The labor inputs are the same, but instead of a front-end loader, a 200-horsepower bulldozer is called for. The cost for this equipment is $78.04 per hour. The listed rate of 1000 cubic yards per day can be converted to square meters per hour with the following calculations.

$$\frac{1000\ \text{yd}^3/\text{day}}{8\ \text{hr/day}} \times 6\ \text{yd}^2/\text{yd}^3 \times 0.836\ \text{m}^2/\text{yd}^2 \times 7/8\ \text{adj} = 549\ \text{m}^2/\text{hr}$$

Dividing this hourly rate into the hourly cost yields dollars per square meter.

Table A.5.9.1 summarizes the foregoing results and shows the combined costs for excavation and spreading. Spreading is the more costly step, and as

TABLE A.5.9.1. Summary of Excavation and Grading Cost Data for Soil Cover

Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment
Excavate	812	0.166	0.043	0.123
Spread and grade	549	0.205	0.063	0.142
Total	549	0.371	0.106	0.265

a result, 549/812 = 0.68 excavation crews would be used for every spreading crew.

A.6 ORCHARDS

Orchards possess two important characteristics affecting decontamination operations. The first is that orchards include ground, leaves, and branches, all of which would become contaminated. Since treatment of one of these may or may not have an adverse effect on another, decontamination of orchards can be more complex than for other areas. Second, the trees necessarily limit vehicular mobility and will completely preclude the use of large trucks.

A.6.1 Water

This operation involves applying water to orchard soil using existing flood irrigation equipment. Water will tend to drive soil contamination down below the surface, helping to reduce hazards due to resuspension and external exposure. It should be pointed out that some orchards have no irrigation system in place, while others may use some other type of irrigation such as drip or center-pivot sprinkling. Any irrigation involving sprinkling has the added advantage of moving some of the radioactive matter from the trees and foliage to the ground.

The sources of information for this operation are various cooperative extension publications including "Costs of Establishing and Producing Prunes," "Almond Production Costs on Class I Soils in Sacramento Valley, 1981," "Almond Production Costs on Class II and Class III Soils in Sacramento Valley, 1981," and "Costs to Establish and Produce Walnuts," all by the University of California Cooperative Extension. Another source was "Cost of Producing Apples in Central Washington," prepared by the Cooperative Extension, College of Agriculture, Washington State University. The information provided in these pamphlets is not always complete. For example, the third publication listed gives the total yearly costs for irrigation but does not indicate how many times the orchard was irrigated. In general, however, all the sources seem to be consistent with the information in the first pamphlet, which indicates about one man-hour of labor required for irrigation for each acre for each application. The cost of this labor was listed at five dollars per hour. Thus, the cost per square meter is

$$\frac{\$5/\text{ac} \cdot 1\ \text{ac}}{4046.7\ \text{m}^2/\text{ac}} \times \frac{8}{7}\ \text{adj} = \$0.0014/\text{m}^2$$

The hourly coverage rate is

$$1\ \text{ac/hr} \cdot 4046.7\ \text{m}^2/\text{ac} \cdot 7/8\ \text{adj} = 3541\ \text{m}^2/\text{hr}$$

A.6.2 Fixative - Aerial Application

Orchards pose a problem of how to apply liquid treatments such as water or a fixative to both the tree foliage and the ground. One technique is to apply these liquids from an airplane or helicopter. In general, however, any fixative, regardless of the method of application, will have reduced effectiveness when the trees are in full leaf. It is essentially impossible to reach every surface with an even application. For this reason, it may be advisable to defoliate the trees before applying the fixative (see Section A.6.4).

There are also some important considerations with respect to the choice of fixative. If the area is to be decontaminated, and the existing trees are to be saved, then a non-toxic material should be used. On the other hand, the difficulty in achieving an even covering of fixative suggests that it may be desirable to use a material that remains sticky for a long time. This would tend to capture particles dislodged by wind or other means. Road oil and diesel oil remain sticky for a long time, but they would be damaging to the orchards themselves. A fixative that might prove appropriate is lignosite. This is relatively inexpensive, and it is non-toxic. However, it may not remain sticky for a sufficient length of time. (See Section A.7.1 for a discussion of fixatives and their characteristics and requirements for application.)

Because leaves and branches raise the total surface per gross land area, we increase the amount of fixative to be applied by 50%, bringing the application rate to 0.75 gallons per square yard. Increasing the amount of material by 50% per unit area also entails a 50% increase in the cost per square meter. As shown in Section A.7.1, the cost per square meter of lignosite at normal application rates is $0.06 per square meter. At the higher application rate the cost rises to $0.09 per square meter.

The cost of application is based on costs developed in Section A.8.1. The rate of application was estimated at 14,000 square meters per hour for an application of 0.4 gallons per square yard. Increasing the amount of fluid applied to 0.75 gallons per square yard will increase the application time by a factor of 0.75/0.4 = 1.875. The new application rate is

$$14{,}000/1.875 = 7467 \text{ m}^2/\text{hr}$$

Hourly labor and equipment costs can be found by further use of the data for aerial application in Section A.8.1. Multiplying the rate (14,000 square meters per hour) by the unit labor cost ($0.01 per square meter) and the unit equipment cost ($0.14 per square meter) gives the hourly costs for these input categories. They are $140 per hour for labor and $1960 for equipment. Dividing these hourly costs by the new application rate gives the adjusted unit labor and equipment costs:

$$\text{Labor:} \quad \frac{\$140/\text{hr}}{7467 \text{ m}^2/\text{hr}} = \$0.019/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$1960/\text{hr}}{7467 \text{ m}^2/\text{hr}} = \$0.262/\text{m}^2$$

Adding the costs of these two inputs to the material cost gives a total cost per square meter of \$0.371.

A.6.3 Fixative - Ground Application

In the previous section, aspects of applying a fixative to orchards were discussed. In this section, the procedure and costs of application of fixative from the ground are presented.

Normal orchard farming procedures include activities that involve application of liquids to the ground and to the trees. For example, ground surfaces are often sprayed with herbicides for weed control using a seed sprayer. A blast sprayer applies chemicals to the tree foliage by spraying a very fine mist into the air. These two sprayers could be used for application of fixative.

In addition to various cooperative extension publications, information was obtained from California and Washington State cooperative extension farm advisors specializing in orchard crops. According to the orchard farm advisor in Butte County, California, costs relating to prune orchards are reasonably representative of orchard costs in general.

The University of California Cooperative Extension publication "Cost of Establishing and Producing Prunes" provides cost and rate data for prune production operations for a 100-acre orchard. For spraying the ground twice with herbicide, the total cost is \$30.65 per acre. Subtracting the cost of materials (\$24) and dividing by the total acres sprayed (one acre sprayed twice is equivalent to two acres) gives \$3.325 per acre. This is comprised of \$1.75 for labor and \$1.575 for fuel and repairs. Converting these figures to a cost per square meter can be done as follows:

$$\text{Labor:} \quad \frac{\$1.75/\text{ac}}{4046.7 \text{ m}^2/\text{ac}} \cdot \frac{8}{7} \text{ adj} = \$0.000494/\text{m}^2$$

$$\text{Fuel:} \quad \frac{\$1.575/\text{ac}}{4046.7 \text{ m}^2/\text{ac}} \cdot \frac{8}{7} \text{ adj} = \$0.000445/\text{m}^2$$

These cost figures are relatively low primarily because a typical application of herbicide is only 50 gallons per acre as compared with a fixative application in the range of 0.2 to 0.5 gallons per square yard. The application of 50 gallons per acre is equivalent to

$$\frac{50 \text{ gal/ac}}{4840 \text{ yd}^2/\text{ac}} = 0.01033 \text{ gal/yd}^2$$

To adjust the cost figures to a level appropriate for fixative, the costs will have to be multiplied by

$$\frac{0.4 \text{ gal/ac}}{0.01033 \text{ gal/ac}} = 39$$

Thus, the labor cost becomes \$0.0193 per square meter, and the fuel cost is \$0.0174.

The equipment cost is estimated differently, using the time to treat a unit area of land. The time to spray one acre once is 0.35 hours with 50 gallons of herbicide. The time required for a 0.4 gallons per square yard coverage would be 39 times longer, and with the adjustment for personnel and equipment decontamination the time would be

$$0.35 \text{ hrs/ac} \times 39 \times 8/7 \text{ adj} = 15.6 \text{ hrs/acre}$$

The hourly cost of the weed sprayer is \$0.50, and the cost of the 30-horsepower tractor to tow the sprayer is \$4.00 per hour. The total hourly cost is, therefore, \$4.50. The equipment cost per acre is

$$\$4.50/\text{hr} \times 15.6 \text{ hrs/ac} = \$70.20/\text{ac}$$

The cost per square meter is

$$\$70.20/\text{ac} \div 4046.7 \text{ m}^2/\text{ac} = \$0.0173/\text{m}^2$$

Adding the labor cost ($\$0.0193/\text{m}^2$), the equipment cost ($\$0.0173/\text{m}^2$), and the fuel and repair cost (\$0.0174) gives the total application cost per square meter of \$0.054. The 15.6 hours per acre time requirement is equivalent to a production rate of

$$\frac{4046.7 \text{ m}^2/\text{ac}}{15.6 \text{ hr/ac}} = 260 \text{ m}^2/\text{hr}$$

Similar calculations using data in "Cost of Producing Apples in Central Washington," released by the Cooperative Extension, College of Agriculture, Washington State University, generated a total cost of \$0.061 per square meter for application. Of this total, labor accounts for \$0.016 per square meter, equipment and repair \$0.034 per square meter, and \$0.010 for fuel.

These cost figures can be compared to the cost of fixative application using a large distributor tank truck as described in Sections A.5.1 and A.5.2. The cost data in A.5.2 show the cost for applying fixative at 0.75 gallons per square yard to be about \$0.0161 per square meter, excluding the cost of the fixative.

The cost of using the orchard spray equipment is considerably higher than that of using the large distributor tank truck because the former is designed for lower-volume applications in areas with restricted access. Since somewhat larger capacity equipment may be useable in some instances, we can view the cost with orchard spray equipment as an upper bound and the cost with the large distributor tank truck as a lower bound.

The pamphlet "Costs of Establishing and Producing Prunes" also provides information on the cost of spraying the trees using a blast sprayer. The time required to spray an acre twice is one hour. The labor cost is \$5.00, and fuel and repairs cost \$10.00. The amount of material applied is 350 to 400 gallons per acre per application. In addition, the sprayer and tractor together cost about \$7.00 per hour. Performing the same calculations as done on the ground spraying data, we get a cost of \$0.00976 per square meter for labor, \$0.01367 for equipment, and \$0.01953 for maintenance and repairs. The implied rate is 512 square meters per hour.

Similar calculations were performed using data from the Cooperative Extension, College of Agriculture, Washington State University publication "Cost of Producing Apples in Central Washington." The resulting labor cost is \$0.0082 per square meter. The equipment cost is \$0.0252 per square meter, and the cost of fuel is \$0.0318 per square meter. The coverage rate is 610 square meters per hour.

Table A.6.3.1 summarizes the results of these calculations and presents representative costs and rates. The representative figures were calculated in four steps. The first was to convert the costs as shown to a dollars-per-hour basis by multiplying the rate by the cost per square meter. Second, the average rate and the average cost per hour for both steps were calculated from the two data sources. Third, the average dollar per hour figure was divided by the average rate to yield the representative dollars per square meter. Finally, the costs for the two steps were added to find the total cost per square meter. The representative combined rate was set equal to the rate of the more costly procedure - spraying the ground. This means that for every operator-tractor-weed sprayer crew there will be one-half an operator-tractor-blast sprayer crew.

Finally, there is the cost of the fixative to be applied. Aspects bearing on the choice of the fixative were discussed in the previous section, and following the reasoning there it is assumed that the fixative chosen is

TABLE A.6.3.1. Summary of Data for Spraying Orchards from the Ground, Excluding Material Cost

Source and Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Fuel
Univ. of Calif.					
Spray ground	260	0.054	0.019	0.017	0.017
Spray trees	512	0.043	0.010	0.014	0.020
Total	260	0.097	0.029	0.031	0.037
Wash. State Univ.					
Spray ground	305	0.060	0.016	0.034	0.010
Spray trees	610	0.065	0.008	0.025	0.032
Total	610	0.125	0.024	0.059	0.042
Representative					
Spray ground	280	0.058	0.018	0.027	0.013
Spray trees	560	0.055	0.009	0.020	0.026
Total	280	0.113	0.027	0.047	0.039

lignosite. Because of the increased total physical surface area per square meter due to tree foliage, the foregoing calculations relating to application assumed that more than the usual amount of fixative per square meter would be required. Those calculations assumed that spraying the ground and spraying the trees would each require about 0.4 gallons per square yard. At this application rate, the material cost for each spraying procedure would be about \$0.05 per square meter. For the two procedures combined the cost would be \$0.10 per square meter. This raises the total cost for the combined spraying operation to \$0.2113.

A.6.4 Defoliate

According to the Cooperative Extension orchard farm advisor in Butte County, California, orchard defoliation is seldom done intentionally any more. The only time it is done is when very heavy wind is expected. Defoliation is a last step to prevent the trees from being blown down.

Defoliation is accomplished by spraying a zinc sulfate solution on the trees. The solution is prepared by mixing eight to ten pounds of zinc sulfate per 100 gallons of water. About 350 gallons of solution are applied per acre. The Cooperative Extension, College of Agriculture, Washington State University publication "Cost of Establishing on Apple Orchard, Columbia Basin, Central Washington" lists the price of zinc sulfate at \$1.35 per pound.

Mixing nine pounds per 100 gallons and spraying 350 gallons per acre means that 31.5 pounds of zinc sulfate are being applied per acre. The cost per square meter for the chemical is

$$31.5 \text{ lbs/ac} \times \$1.35/\text{lb} \div 4046.7 \text{ m}^2/\text{ac} = \$0.0105/\text{m}^2$$

Table A.6.4.1 summarizes the data from the University of California Cooperative Extension publication "Cost of Establishing and Producing Prunes" and the Cooperative Extension, College of Agriculture, Washington State University publication "Cost of Producing Apples in Central Washington." This is the same data used in the previous section for calculating the cost of applying fixative to trees. As shown, the hourly labor, equipment, and fuel costs are averaged along with the time to spray one acre with 350 gallons. This average time is converted to a rate in terms of square meters per hour and adjusted for one hour per shift lost to radiation control measures. This is done as shown:

$$4046.7 \text{ m}^2/\text{ac} \div 0.425 \text{ hr/ac} \times 7/8 \text{ adj} = 8331 \text{ m}^2/\text{hr}$$

Dividing this rate into the hourly cost figures gives the labor, equipment, and fuel cost per square meter. Adding the material cost brings the total to \$0.0333 per square meter.

A.6.5 Leach

The general aspects of leaching were described in Section A.4.3. As in the case of leaching lawns, it seems the appropriate method for leaching orchards is first to apply a concentrated solution of the leaching agent to the

TABLE A.6.4.1. Summary of Data for Applying Defoliant to Orchard Trees

Source	Time or Rate	Cost (1982 $/m^2)					
		Units	Total	Labor	Equipment	Material	Fuel
Univ. of Calif.	0.5 hr/ac	$/hr:	---	5.00	7.00	---	10.00
Wash. State Univ.	0.35 hr/ac	$/hr:	---	5.00	18.43	---	23.29
Average	0.425 hr/ac	$/hr:	---	5.00	12.72	---	16.64
Representative	8331 m^2/hr	$/m^2:	0.0146	0.0006	0.0015	0.0105	0.0020

soil and to follow this with an application of water. Following Section A.4.3, we base the calculations on ferric chloride being used as the leaching agent. Dick and Baker (1967) used this material in a 1% solution in their tests at the Nevada Test Site. Other chemicals could be used, notably EDTA.

The cost of applying ferric chloride is estimated here using the representative cost of applying fixative to the ground, which was developed in Section A.6.3. This cost is adjusted to account for the different amount of material applied.

Ferric chloride is normally sold in a 40% solution. One gallon of this mixture will cover 19 square meters to produce a 1% solution when 0.3 inch of water is applied to the soil. One gallon for 19 square meters is equivalent to 213 gallons per acre. Fixative application, at 0.4 gallon per square yard, is equivalent to 1936 gallons per acre. Thus, applying the leaching agent involves a fraction of the cost and time that applying fixative does:

$$213 \div 1936 = 0.110$$

Adjusting the application rate with this factor gives 2545 square meters per hour. The labor cost is $0.00198 per square meter, and the equipment and fuel costs are $0.00297 and $0.00143 per square meter, respectively.

In addition to the cost of applying the leaching agent, there is also the cost of the leaching agent itself. This was calculated as $0.026 per square meter in Section A.4.3. Finally, the cost of applying water was estimated in Section A.6.1. The various costs for leaching are summarized and combined in Table A.6.5.1.

TABLE A.6.5.1. Summary of Leaching Data

Item	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material	Fuel
Ferric chloride	--	0.026	--	--	0.026	--
Application of ferric chloride	2545	0.0064	0.0020	0.0030	--	0.0014
Application of water	3541	0.0014	0.0014	--	--	--
Total	2545	0.0338	0.0034	0.0030	0.026	0.0014

A.6.6 Scrape Without Tree Removal

This operation involves removing the top four to six inches of orchard soil without removing or damaging the trees. The requirement to work around the trees makes this operation significantly different from scraping agricultural fields (A.5.5) or vacant land (A.7.5). There are four principal ways in which scraping will be affected by the presence of trees. First, any earthmoving equipment used will have to be fairly small to fit between the trees. Second, such equipment will be limited in movement by the trees. Third, dump trucks will not always be able to get close to the spot where the scraping is being done. Fourth, shallow roots and the base of the trunk will require careful equipment operation if damage to the trees is to be avoided.

A workable procedure for scraping appears to be to have two laborers shovel soil from the base of the trees toward the center of the lanes between the tree rows. These would be followed by a small (0.75 cubic yard capacity) wheel-mounted front-end loader. The front-end loader would scrape up the top surface of the soil and remove the soil to a dump truck waiting at the end of the lane.

Means' Building Construction Cost Data 1982 provides data useful for estimating the cost of this operation. The hand shoveling would require two building laborers at $19.40 per hour each. A medium-equipment operator at $24.95 per hour and 0.5 building laborers are specified for operating the front-end loader. Total hourly labor costs (including fringe benefits) are $73.45. The front-end loader costs $24.00 per hour.

Estimating the rate is more conjectural. Means lists the output of the small front-end loader as 45 cubic yards per hour for bulk excavation of medium soil. As mentioned earlier, the orchard places severe limitations on the equipment's productive efficiency. On the other hand, the soil is likely to be relatively soft and light, and the terrain fairly flat and free of excess brush and weeds. Based on these considerations, we estimate the (unadjusted) production rate at 75% of that listed by Means. The coverage in terms of square meters per hour can be calculated as follows:

$$45 \text{ yd}^3/\text{hr} \times 0.75 \text{ eff. adj} \times 6 \text{ yd}^2/\text{yd}^3 \times 0.836 \text{ m}^2/\text{yd}^2 \times 7/8 \text{ adj}$$
$$= 148 \text{ m}^2/\text{hr}$$

In comparison, Ed Doolittle of Doolittle Construction Co. supplied data indicating a faster rate. This faster rate is largely the result of his specifying a larger-capacity front-end loader. He estimated that a front-end loader with a three cubic yard capacity could load a scoopful into a dump truck once every three minutes. This is equivalent to one cubic yard per minute or 60 cubic yards per hour. This is one-third more than the full rate given by Means for the smaller loader. Converting the Doolittle figure to square meters per hour, we get

$$60 \text{ yd}^3/\text{hr} \times 6 \text{ yd}^2/\text{yd}^3 \times 0.836 \text{ m}^2/\text{yd}^2 \times 7/8 \text{ adj} = 263 \text{ m}^2/\text{hr}$$

Here we use the rate calculated from the Means data since the smaller equipment seems more appropriate in this situation. Further, the rate can be adjusted with better information simply by changing the efficiency adjustment factor from 75% to a different level.

Dividing the hourly rate into the hourly labor and equipment costs generates their respective costs in terms of dollars per square meter: \$0.496 and \$0.162. The total cost per square meter is \$0.658.

A.6.7 Plow

Section A.5.6 provides a general description of plowing as a decontamination technique. In an orchard, however, plowing will be hampered by the trees. Also, according to the Cooperative Extension orchard farm advisor in Butte County, California, unless the orchard has been cultivated on a regular basis, roots may be so shallow that any plowing-type operation may be impossible without severe permanent damage to the trees.

This source indicated that the particular plowing-type operation appropriate for orchards is called disc and float. This mixes more than turns the soil, and it limits damage to the root structure. A standard ten-inch disc harrow will mix the soil well to a depth of four to five inches. Floating does little more than leveling out the ridges left by the disc. The cost information provided indicated that normal orchard operations entail expenditures of about \$100 per acre per year for discing and floating. The procedure is performed five times per year. The rate given was 2.2 acres per hour, but as will be explained, this is probably an inadvertent error and the rate is more likely 2.2 hours per acre.

In the University of California Extension publication "Costs to Establish and Produce Walnuts," the time required for disc and float five times is 2.2 hours per acre. This same rate is repeated elsewhere in the publication. The estimate of 2.2 hours per acre for performing the operation five times is equivalent to 0.44 hours to disc and float one acre once. The farm advisor's 2.2 acres per hour for five treatments implies one fifth of an hour to disc 2.2 acres once. In other words, the hourly coverage rate is 11 acres. This seems unreasonably high. Further, the publication-listed rate of 2.2 hours per acre is consistent with the listed labor cost of \$11 per acre. This works out to \$5.00 per hour, which is the normal agricultural labor wage rate.

At 2.2 hours per acre for disc and float five times, the rate in square meters per hour is

$$\frac{5}{2.2\ \text{hrs/ac}} \times 4046.7\ \text{m}^2\text{/ac} \times \frac{7}{8}\ \text{adj} = 8047\ \text{m}^2\text{/hr}$$

For comparison, the rate for plowing agricultural fields is 8500 square meters per hour.

"Costs to Establish and Produce Walnuts" lists the labor cost for discing and floating as \$11.00 per acre and the fuel and repair costs as \$15.75 per acre. In addition, a 60-horsepower wheel-mounted diesel tractor costs \$7.00 per hour to operate, and the disc and float equipment cost \$1.15 and \$1.00 per hour, respectively. It is not clear if these figures include the cost of ownership, but since purchase price, depreciation, and interest are listed separately, it appears that the hourly operation costs do not include these other items. The cost of the tractor is $20,000, and that of both the associated implements is $5,000, for a total of $30,000. This $30,000 comprises about 13.9% of the total $216,200 farm equipment investment. This source gives the depreciation and interest per acre for the total equipment investment as $216.00 and $151.34, respectively. Taking 13.8% of these figures as the share for discing and floating equipment, we get a depreciation cost of $30 per acre per year and $21 per acre per year for interest. The total of these two costs is $51.00. However, since this equipment is used for other farming activities besides discing and floating, only a fraction of this cost can be ascribed to that procedure, and, unfortunately, this source does not provide sufficient information to determine that fraction.

Another approach is to refer to Means' Building Construction Cost Data 1982. This source (p. 10) lists the monthly rent for a 65-horsepower wheel-mounted tractor equipped as an earthloader. Assuming that the additional five horsepower and the loader equipment are roughly equivalent in cost to the disc and float equipment, we take the monthly ownership cost to be $1875. Dividing by 336 hours per month, we get an hourly equipment ownership cost of $5.58. Total equipment cost is, therefore, the sum of this figure and the operation costs. The total is $14.73 per hour.

Dividing the hourly costs by the coverage per hour gives $0.006 per square meter for labor, $0.0018 per square meter for equipment, and $0.0020 per square meter for fuel and repairs. Adding these gives a total cost of $0.0044 per square meter.

A.6.8 Remove and Replace

The most costly orchard decontamination operation is removing and replacing the trees. This operation has three cost components. They are removal of trees, ground preparation and planting of trees, and the trees themselves. This operation might be done in conjunction with soil scraping. If this were the case, the appropriate stage for the scraping to be done would be after tree removal, but before ground preparation. Soil scraping with the trees removed is listed as a separate operation (see Section A.6.12).

Not included in the cost estimates here are the loss in income from unrealized crop sales. It is assumed that if orchard removal and replacement were necessary, the crop would not be safe for use. Another consideration is that the newly planted trees will not yield a marketable crop for several years. This loss in income, as well as the necessary post-planting orchard care costs, are accounted for in reduced property value. They are not counted as part of the removal and replacement operation cost.

Orchards differ considerably among themselves due to local conditions as well as the type of crop being raised. The two main factors which affect removal and replacement costs are the number of trees per acre and the cost of the trees.

The Cooperative Extension, College of Agriculture, Washington State University publication "Determining the Costs of Removing and Replacing Dead or

Damaged Commercial Fruit Trees" is the primary source of information about the removal of trees. The cost data were adjusted from 1977 to 1982 price levels. In addition, conversation with the Cooperative Extension orchard farm advisor in Yakima, Washington, provided supplemental descriptive information. Removal of trees is relatively straightforward, involving nothing more than tying the tree to a pickup truck or small tractor with a rope or a chain and using the vehicle to uproot the tree. However, it may be necessary to use a bulldozer and backhoe to remove large trees. The Cooperative Extension report mentioned above estimates the labor time for removing five trees at three man-hours, using two farm laborers. The 1982 cost for farm laborers is given in other Cooperative Extension publications mentioned elsewhere in this Appendix as \$5.00 per hour. The equipment time for removing five trees is listed as 1.5 hours. Assuming that a pickup truck costing \$9.00 per hour is used, the equipment cost is \$13.50. Dividing these costs by five, we get \$3.00 per tree for labor and \$2.70 per tree for equipment. The time required per tree is 0.3 hours.

Next it is necessary to estimate the number of trees per acre so that costs per tree can be converted to cost per square meter. Various Cooperative Extension publications list representative numbers of trees per acre for various types of crop. The numbers vary widely. For example, typical walnut orchards may have 48 trees per acre, while there may be 269 trees per acre in a red delicious apple orchard. Other examples are almond, 75 per acre; apricot, 75 per acre; cherry, 108 per acre; orange, 136 per acre; fig, 95 per acre; kiwi, 150 per acre; olive, 97 per acre; peach, 108 per acre; pistachio, 130 per acre; and prune, 108 per acre. Here we assume 120 trees per acre.

Multiplying 120 trees per acre by 0.3 hours per tree for removal gives a time per acre of 36 hours. The rate in terms of square meters per hour is:

$$\frac{4046.7 \text{ m}^2/\text{ac}}{36 \text{ hr/ac}} \times \frac{7}{8} \text{ adj} = 98 \text{ m}^2/\text{hr}$$

Dividing this into the hourly labor cost for the two workers gives:

$$\frac{2 \times \$5.00/\text{hr}}{98 \text{ m}^2/\text{hr}} = \$0.102/\text{m}^2$$

The equipment cost, calculated similarly, is \$0.092 per square meter. The total cost for removing trees is, therefore, \$0.194 per square meter.

Next to be considered is the cost of preparing the site for replacing the trees. Note, however, that if the soil is to be scraped (see Section A.6.12) or covered with clean soil (see Section A.6.10), these operations would be done before this site preparation.

According to the Cooperative Extension publication "Determing the Costs of Removing and Replacing Dead or Damaged Commercial Fruit Trees," two laborers and one pickup truck working for one hour are required for every five trees. In addition, this source calls for \$4.50 of new soil. The costs per hour are labor, \$11.00; equipment, \$9.00; and materials, \$4.50.

At five trees per hour, the coverage rate is:

$$\frac{4046.7\ m^2/ac}{120\ trees/ac} \times 5\ trees/ac \times \frac{7}{8}\ adj = 148\ m^2/hr$$

Dividing the hourly coverage rate into the hourly costs gives:

Labor: $\frac{\$5.00/hr \times 2}{148\ m^2/hr} = \$0.068/m^2$

Equipment: $\frac{\$9.00/hr}{148\ m^2/hr} = \$0.061/m^2$

Materials: $\frac{\$4.50/hr}{148\ m^2/hr} = \$0.030/m^2$

Summing these gives the total cost of site preparation as $0.159 per square meter.

According to the same source, tree planting involves equipment to haul the trees such as a pickup truck and four laborers to dig the hole and drive the truck. The hourly labor cost is, therefore, $20, and the equipment cost is $9 per hour. Five trees can be planted in an hour. As with site preparation, the hourly coverage rate is 148 square meters per hour. The costs per square meter are:

Labor: $\frac{\$5.00/hr \times 4}{148\ m^2/hr} = \$0.135/m^2$

Equipment: $\frac{\$9.00/hr}{148\ m^2/hr} = \$0.061/m^2$

Total: $\$0.196/m^2$

A set of publications from the University of California Cooperative Extension provides additional information. They are "Costs of Establishing and Producing Prunes," "Costs to Establish and Produce Walnuts," and "Almond Establishment Costs on Class II and III Soils in Sacramento Valley." Because these pamphlets deal with establishing a new orchard rather than replacing an old one, no cost data were given for removing trees. Also, since these sources deal with establishment of an entire orchard while the other report is concerned with replacement of five trees, equipment, procedures, and costs differ. In particular, establishment of a whole orchard permits the farmer to take advantage of economies of scale in large equipment.

"Costs of Establishing and Producing Prunes" lists the total pre-plant and planting costs as $210 per acre. Converting to dollars per square meter and adjusting for an hour per shift lost to radiation control measures, we get:

$$\$210/\text{ac} \div 4046.7\ \text{m}^2/\text{ac} \times 8/7 = \$0.059/\text{m}^2$$

"Costs to Establish and Produce Walnuts" gives the preparation and planting costs as $227 per acre. This works out to $0.064 per square meter. The report on establishing an almond orchard lists the cost as $181 per acre for soil preparation and planting. Using the same calculations, we get $0.051 per square meter. Unfortunately, these sources do not provide information on costs by input or production rates.

Comparison of the total site preparation and planting costs from the Washington State University Cooperative Extension publication ($0.355 per square meter) with the figures from the University of California Cooperative Extension publications (prunes, $0.059 per square meter; walnuts, $0.064 per square meter; almonds, $0.05 per square meter) reveals a considerable discrepancy. The information from the first source is for operations on a limited scale. Also, the figures are described as illustrative, while those from the other sources are intended to be accurate estimates of actual costs. For these reasons, we take the base for estimating the representative total site preparation and planting costs as in the range of costs from the University of California Cooperative Extension publications: $0.060 per square meter. Adjusting this for an hour lost per shift due to the radiation, we get

$$\$0.06/\text{m}^2 \times 8/7\ \text{adj} = \$0.069/\text{m}^2$$

Determining the representative rate and input costs is done as follows. The inputs specified by the Washington State University Cooperative Extension publication included six farm laborers and two pickup trucks. The methods employed in the larger-scale site preparation and planting activities implicit in the University of California Cooperative Extension publications suggest greater capital intensity. Therefore, the crew assumed is one 60-horsepower wheel-mounted diesel tractor, with additional equipment such as a landleveler and a pickup truck. The total hourly cost of this equipment is about $22.00. Labor consists of one skilled farm laborer at $6.50 per hour and three farm laborers at $5.00 per hour. The total labor cost is $21.50.

The total hourly cost for labor and equipment is $43.50. The rate implied by this hourly cost and the $0.069 cost per square meter is 630 square meters per hour. The input costs in terms of dollars per square meter are:

$$\text{Labor:}\quad \frac{\$21.50/\text{hr}}{630\ \text{m}^2/\text{hr}} = \$0.034/\text{m}^2$$

$$\text{Equipment:}\quad \frac{\$22.00/\text{hr}}{630\ \text{m}^2/\text{hr}} = \$0.035/\text{m}^2$$

The price of trees to be planted depends on the type of tree and the tree's age. Inspection of various publications from the Cooperative Extension, College of Agriculture, Washington State University, and the University of California Cooperative Extension revealed tree prices ranging from $1.50 for almond and fig trees to $8.50 for a kiwi tree. Other examples are apple, $4.10; walnut, $8.00; prune, $3.00; apricot, $2.00; cherry, $2.85; citrus, $4.35; olive, $1.55; peach, $1.43; pistachio, $3.00; and pear, $1.52. We use the price of apple trees, $4.10, as representative. At 120 trees per acre, the cost per square meter for the trees is:

$$\frac{120 \text{ trees/ac} \times \$4.10\text{/tree}}{4046.7 \text{ m}^2\text{/ac}} = \$0.122/\text{m}^2$$

Table A.6.8.1 presents the costs of the three cost components of orchard removal and replacement and the total costs. Removal is the most costly procedure, and therefore the rate for the whole operation is set equal to the

TABLE A.6.8.1. Summary of Orchard Removal and Replacement Data

Item	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Removal	98	0.194	0.102	0.092	
Site preparation and planting	630	0.069	0.027	0.033	
Trees	--	0.122	--	--	0.122
Total	98	0.385	0.129	0.125	0.122

removal rate, 98 square meters per hour. This means that 98 ÷ 630 = 0.16 site preparation and planting crews would be used for each removal crew.

A.6.9 Radical Pruning

Radical pruning is an operation intended to remove radioactive contamination from orchards by removing significant portions of the trees themselves. The Cooperative Extension, Butte County, California, orchard farm advisor advises that, with such pruning, at least one branch should be left unpruned. This will enable the roots to be fed and thereby keep the tree alive.

This source estimates that the cost to perform this operation would be about $250 per acre. This compares with normal dormant pruning costs of about $100 per acre, depending on the type of trees. This estimate for normal pruning costs was confirmed by three University of California Cooperative Extension publications, "Costs of Establishing and Producing Prunes," "Costs to

Establish and Produce Walnuts," and "Almond Production Costs on Class II and III Soils in Sacramento Valley."

The farm advisor added that the rate of radical pruning would be about two acres per man-day. This rate is considerably faster than normal pruning rates. Data from the above-mentioned publications indicates that for prune orchards the rate would be about 0.30 acres per man-day, for walnut orchards that rate would be about 0.8 acres per man-day, and for almonds the rate would be about 0.67 acres per man-day. In addition, the cost figure given ($250 per acre) is difficult to resolve with the two acres per man-day rate because this implies a cost of $500 per day per worker.

In order to resolve these difficulties, we assume the $250 per acre cost estimate to be accurate, but we estimate a slower rate consistent with the hourly costs of an appropriate set of inputs. In this matter, examination of the publications mentioned shows that only walnut pruning requires any special equipment. Because of the greater height of walnut trees, two powered towers to enable the upper branches to be reached are specified. For radical pruning, however, it is unlikely that towers would be necessary even for large trees. This is because radical pruning does not call for pruning the ends of the branches, but instead calls for cutting off the branches themselves. The equipment that would be necessary includes power and manual saws, ladders, and a pickup truck or a larger truck. The pamphlet "Cost of Producing Apples in Central Washington," by the Cooperative Extension, College of Agriculture, Washington State University, provides cost data on these items as shown in Table A.6.9.1.

TABLE A.6.9.1. Cost Data for Radical Pruning Equipment from the Cooperative Extension, College of Agriculture, Washington State University

Item	Cost (1982 $/hr)
Pickup, 1/2 ton	8.04
Pruning tools	0.04
Ladders	0.10
Chainsaw	5.95
Total	14.13

We assume that two farm laborers, at $5.00 per hour each, comprise the labor component of the inputs. Thus, the total hourly cost is $24.13. At this rate, the (unadjusted) time for one acre is

$$10.4 \text{ hr/ac} \times 8/7 \text{ adj} = 11.9 \text{ hr/ac}$$

This is equivalent to

$$4046.7 \text{ m}^2\text{/ac} \div 11.9 \text{ hr/ac} = 340 \text{ m}^2\text{/hr}$$

Dividing this hourly production rate into the hourly input costs yields:

Labor: $\$10/hr \div 340\ m^2/hr = \$0.029/m^2$

Equipment: $\$14.13 \div 340\ m^2/hr = \$0.042/m^2$

Total: $\$24.13 \div 340\ m^2/hr = \$0.071/m^2$

A.6.10 Cover, Trees Removed

This operation involves covering the ground with six inches of uncontaminated soil after the trees have been removed. Covering may or may not be done following scraping of contaminated soil. The covering operation is identical to covering agricultural fields. See Section A.5.9 for a discussion of the cost estimates.

A.6.11 Cover, Trees in Place

This operation is the same in principle to covering the soil with uncontaminated soil as described in the previous section. However, with the trees in place, it would not be possible to use large earthmoving equipment without damaging the trees.

The operation has three steps, the costs of which are estimated separately. The first step is the excavation and loading of the uncontaminated soil. The estimated cost of this procedure was discussed in Section A.5.9. The second step involves hauling the soil to the site. This cost is a function of the distance the soil is to be hauled and is calculated separately in the program. The third step is the spreading of the soil. The estimated cost of this procedure is developed in this section. Also, the combined excavation and spreading cost is calculated.

The basic source of information for this operation is Means' Building Construction Cost Data 1982. The basic piece of equipment necessary is a small bulldozer or a small front-end loader to move the delivered soil out to the orchard and spread it. For a 75-horsepower bulldozer, Means lists the daily output at 400 cubic yards with a 50-foot haul. For a 150-foot haul the daily output is 200 cubic yards. In general, for most such equipment, an increase in the haul distance causes similar decreases in daily output. Here we assume that output is equal to half that of the 150-foot haul. The implicit assumption is that the average haul is 300 feet and the (unadjusted) output is 100 cubic yards per day. Assuming a coverage depth of six inches, each cubic yard of soil will cover six square yards. The resulting coverage rate after productivity adjustment and conversion to square meters is

$$100\ yd^3/day \div 8\ hrs/day \times 6\ yd^2/yd^3 \times 0.836\ m^2/yd^2 \times 7/8\ adj$$
$$= 55\ m^2/hr$$

The bulldozer is listed (p. vii) as having a daily cost of $189.85, or $23.73 per hour.

For operation of the bulldozer, Means specifies one medium-equipment operator at $24.95 per hour and 0.5 building laborers at $19.40 per hour. In addition, another two building laborers would be required for handwork around the base of trees. The total hourly labor cost is, therefore:

1	Equipment operator	at $24.95/hr =	$24.95/hr
2.5	Building laborers	at $19.40/hr =	$48.50/hr
		Total =	$73.45/hr

Dividing the hourly coverage rate into the hourly input costs gives the costs in square meters:

Labor: $\$73.45/\text{hr} \div 55\ \text{m}^2/\text{hr} = \$1.34/\text{m}^2$

Equipment: $\$23.73/\text{hr} \div 55\ \text{m}^2/\text{hr} = \$0.43/\text{m}^2$

Total: $\$97.18/\text{hr} \div 55\ \text{m}^2/\text{hr} = \$1.77/\text{m}^2$

Table A.6.11.1 shows the costs of soil excavation and spreading. The total for the two procedures is also presented. In order to equalize the rates of the two procedures, 0.07 excavation crews would be used for every spreading crew. The combined crew would consist of 1.07 medium-equipment operators, 2.54 building laborers, 0.07 front-end loaders, and one 75-horsepower bulldozer or small front-end loader.

TABLE A.6.11.1. Summary of Cost Data for Soil Covering in Orchard, Trees in Place

Procedure	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment
Excavate	812	0.17	0.04	0.13
Spread	55	1.77	1.34	0.43
Total	55	1.94	1.38	0.56

A.6.12 Scrape, Trees Removed

This operation would be used in conjunction with orchard removal and replacement. The execution of scraping with the trees removed is the same as scraping agricultural fields as described in Section A.5.5. However, because of the depressions and other irregularities in the soil resulting from tree removal, this operation will have a lower decontamination efficiency.

A.7. VACANT LAND

Vacant land refers to land with no structural or agricultural improvements. Ground cover consists of primarily grasses and bushes rather than trees. This general description is meant to distinguish this land type from agricultural land and forest land, which are discussed separately.

A.7.1 Fixatives

The term "fixative" refers to any material used to bind radioactive particles to a surface. Fixing radioactive contamination to a surface will prevent resuspension of the particles in the air by wind or by other physical disturbance. This will help prevent the spreading of contamination, recontamination of treated surfaces, excess contamination of equipment, and additional radiation hazard to personnel. There are a number of materials that could be used for this job, including petroleum-based products such as road oil, emulsified asphalt, and MC-70. Other products that might be useful include those that are sold for the purpose of dust control. These are sometimes called "dust palliatives," "dedustants," or "dust retardants" and include generic products such as calcium chloride, magnesium chloride, and calcium lignosulfate, and proprietary products such as Coherex and Compound SP.

In addition, there are other materials that could be used as fixatives, although that is not their primary function. For example, an application of strippable coating would be effective, though relatively costly (see A.1.6). Also, decontaminating foam could be considered a very short-lived fixative (see A.1.5). In some circumstances, even plastic sheeting or water could be used to prevent resuspension of radioactive particles. The important aspects in the choice and application of a fixative are discussed in the remainder of this section.

The use and costs of road oil as a fixative are presented elsewhere in this Appendix (e.g., Section A.1.10) so it is not necessary to repeat in detail these findings. The essential points are that road oil can be used as a fixative, and the cost of the material is about $0.31 per square meter. The term "road oil" actually refers to a number of products having differing viscosities. These are classified as SCs, and common grades are SC-70, SC-250, SC-800, and SC-3000. Road oil does have certain disadvantages. It is quite messy and, in that respect, may diminish property values and raise cleanup costs. Also, because road oil contains a diesel-like dilutant, it is slow curing, remaining sticky for an extended period of time. This can be an advantage to the extent that it continues to capture, as well as hold, dust for an extended period. Finally, widespread application of road oil will have damaging environmental effects.

Another petroleum-based product, MC-70, is used by Reynolds Electrical and Engineering Company, Inc. (REECo), at the Nevada Test Site. According to sources at Chevron Asphalt Co. and Shell Oil Co., MC-70 is a "cut-back asphalt"; that is, asphalt diluted, or "cut back," with a kerosene distillate. There are several MC products, such as MC-70, MC-100, MC-250, MC-800, and MC-3000. The higher-numbered MCs have greater viscosity, which is controlled by the amount of dilutant. MC-70, being of low viscosity, has high penetrating power due to the relatively high proportion (45%) of dilutant.

MC-70 is applied at 110-135^{o}F. The normal coverage is from 0.1 to 0.5 gallons per square yard, more of the product being required when the soil is porous and absorbant. After curing, MC-70 will form a thin membrane over the soil surface. However, this membrane would break if someone were to walk on it or drive a vehicle over it.

Prices of MCs vary by grade (viscosity), location, and manufacturer. Chevron, which does not sell MC-70, said their price for MC-100 ranges from about $185 to $215 per ton with 255 to 260 gallons per ton (at 60°F). This comes to about $0.78 per gallon. Shell quoted a price of $165 per ton, F.O.B. their plant in California. At 7.93 pounds per gallon, this comes to 252 gallons per ton, or about $0.65 per gallon. Assuming an average coverage rate of 0.4 gallons per square yard, the cost per square meter works out to

$$\$0.78/\text{gal} \times 0.4\ \text{gal/yd}^2 \times 1.09\ \text{yd}^2/\text{m}^2 = \$0.34/\text{m}^2$$

for the Chevron price, and

$$\$0.65/\text{gal} \times 0.4\ \text{gal/yd}^2 \times 1.09\ \text{yd}^2/\text{m}^2 = \$0.28/\text{m}^2$$

for the Shell price. Since the Shell price is F.O.B. their plant, $0.34 per square meter is taken as a representative figure for MC-70 (or MC-100).

According to the source at Chevron Asphalt, emulsified asphalt may be a better choice for a soil fixative for three reasons. First, it does not have to be heated before application. Second, since it is water based, it is easier to handle. Third, it is less costly than road oil or MC-70. Prices range from $135 to $150 per ton according to Chevron and Shell. At 8.3 pounds per gallon, the per-gallon price is from $0.56 to $0.62. Applied at 0.4 gallons per square yard, the cost of the material would be from $0.27 to $0.30 per square meter. We take the higher figure as representative. Possible drawbacks to using emulsified asphalt are reduced penetrating power and a tendancy of the treated soil to ball up when a vehicle is driven over it.

Additional discussion of petroleum-derived fixatives is given in Section A.1.8 (tack coat) and Section A.1.9 (sealer).

Coherex is made by the Witco Co. This product is a liquid emulsion of petroleum resins, making a "clean" material compared with MCs, road oil, and emulsified asphalt. Further advantages are that Coherex is non-toxic and is diluted with water for application. In consequence, the environmental problems are significantly less with this product than with the other petroleum-based products. Coherex is commonly used on dirt roads and to protect stockpiles, such as those of coal, from producing dust.

Before application, Coherex is mixed with water in ratios ranging from one part Coherex to four parts water, to a ratio of one part Coherex to twenty parts water. The 1:20 ratio is used with frequent repeat applications, as would be necessary on surfaces with frequent vehicle or foot traffic.

When purchased in bulk, the price is $0.95 per gallon F.O.B. The shipping cost from the Bakersfield, California, plant to the state of Washington, a distance of about a thousand miles, would be about $0.30 per gallon. If we use this as a representative shipping cost, the total cost per gallon is about $1.25. The company's representative explained that a typical application would involve a dilution of five parts water to one part Coherex. This mixture would be applied at about 0.75 gallons per square yard. This implies a cost of $0.19 per square meter for the product and for shipping, but not including the cost of application. The mixture is applied as a spray using water tank trucks. This 1:5 mixture would normally last for about six months, when the application should be repeated. Thereafter, annual applications should suffice. This means that, unlike other decontamination steps which, once accomplished, have permanent effects, the cost of the fixative is a function of the desired duration of the dust suppression. Further, since applications involve costs through time, the cost of a fixative of any particular duration requires discounting. The algebraic expression of the cost of a fixative requiring repeated applications with the timing pattern just described discounted back to the date of the initial application is

$$C = c_0 + \frac{c_{1/2}}{(1 + r)^{1/2}} + \frac{c_1}{(1 + r)^1} + \frac{c_2}{(1 + r)^2} + \ldots + \frac{c_{j-1}}{(1 + r)^{j-1}}$$

$$= \sum_{i = 0,\ 1/2,\ 1,\ 2,\ 3,\ \ldots}^{j-1} \frac{c_i}{(1 + r)^i}$$

where C = present value of fixative costs
c_i = cost of the i^{th} application
j = desired duration
r = discount rate

If the application costs are all the same, such that

$c_i = c$ all i

then

$$C = c \sum_{i = 0,\ 1/2,\ 1,\ 2,\ 3,\ \ldots}^{j-1} \frac{1}{(1 + r)^i}$$

Another product that could be used as a fixative is Compound SP, made by Johnson March, Inc. This is an organically based long-chain polymer. It can be sprayed on with an orchard sprayer or a spreader truck as is used to apply road oil. The result is a clear, crusty latex surface coating. Sold in 55-gallon drums, the liquid is applied undiluted at about 1 gallon for 100 square feet, which is equivalent to 0.09 gallon per square yard, or 0.11 gallon per square meter. Coated surfaces should have 24 hours to cure without rain. After that period, the coating will withstand heavy rain.

There are actually two SP products, SP-301 and SP-400. A coating of Compound SP-301 will last about a year. When buying in large quantities (more than 45 drums), the price is \$2.15 per gallon. At one gallon per 100 square feet, the cost per square meter is \$0.23. With the addition of an assumed \$0.30 per gallon shipping cost, the cost per square meter would be about \$0.26. The present value of the cost of using Compound SP-301 as a fixative for a duration of j years can be calculated in the following manner:

$$C = c \sum_{i = 0, 1, 2, \ldots}^{j-1} \frac{1}{(1 + r)^i}$$

The terms here have the same definitions as before. This formulation assumes that each application has the same cost.

The other product, SP-400, is more concentrated and will last three to four years. At \$3.95 per gallon, the cost per square meter is about \$0.42. With a shipping cost of \$0.30 per gallon, this cost per square meter will rise to \$0.46. Assuming that each application will last for three years, the present value of the fixative cost for a duration of j years is

$$C = c \sum_{i = 0, 3, 6, 9}^{j-3} \frac{1}{(1 + r)^i}$$

Again, all terms have the same meaning as before, and it is assumed that each application will have the same cost.

Compound SP forms a coating over the soil, but this coating will not support a load. While it has some flexibility, if it is deformed more than 0.25 or 0.50 inches, it will break. Once broken, wind can lift and rip the coating, because Compound SP does not penetrate the soil. Compound SP will transmit moisture, and it will not prevent plants from growing. In fact, sprouting plants will puncture the membrane and might reduce its effectiveness. Compound SP could be used on other surfaces such as roofs or walls. However, since the material will bind with the surface like paint, it cannot be removed easily.

The Dow Chemical Company makes and sells calcium chloride in pellet, flake, and liquid forms for the purpose of dust control. The trade names for these products are Peladow, Dowflake, and Liquidow, respectively. According to the manufacturer, calcium chloride works by attracting moisture from the air as it tries to return or remain in its natural liquid state. It then forms a thin liquid coating over the material on which it is placed. The moisture increases interparticle cohesion in the same manner as does water appplied to dusty soil. The chemical has a tendency to hold the moisture so that dust suppression is maintained. However, in very arid areas the soil will dry out, necessitating periodic applications of water.

Glenn Clayton, with REECo, advised that two products with which his company has had good success in dust suppression, and which he feels would also work well as fixatives, are Polybinder and magnesium chloride. Both of these products are purchased from Burris Oil in Las Vegas, Nevada. The following information on these two fixatives came from both sources.

Polybinder is a wood pulp product, sodium lignin with sugars. It is sold in liquid form at a price of $0.80 per gallon. With shipping, the cost comes to about $1.25 per gallon. The manufacturer indicated that Polybinder should be diluted with about an equal part of water. The source with REECo said that they applied Polybinder undiluted. This higher concentration is probably necessitated by heavy road traffic. An oil- or water-spreader truck is used to apply the fixative at about 0.5 gallons per square yard. Polybinder is applied at air temperature. The normal application rate at the Nevada Test Site is about 6,000 gallons per day per truck, which equals a coverage of 12,000 square yards per shift.

Magnesium chloride is sold at $0.50 per gallon. With shipping, the cost would be about $0.80 per gallon. According to the manufacturer, magnesium chloride should normally be diluted, with one part magnesium chloride to four parts water. The diluted solution is applied in the same way as Polybinder.

Both products work by drawing and holding moisture from the air. However, according to the source at Burris Oil, Polybinder works better than magnesium chloride. This is due in part to the stickiness of the sugars in Polybinder. Also, both these products have relatively short lives, lasting only about three months.

Using the $1.25 per gallon for the undiluted Polybinder and $0.80 per gallon for the magnesium chloride, we can calculate the cost of materials per square meter. For Polybinder the cost is

$$\$1.25/\text{gal} \times 0.5 \text{ gal Poly./gal diluted sol} \times 0.5 \text{ gal/yd}^2 \times 1.1947 \text{ yd}^2/\text{m}^2 = \$0.37/\text{m}^2$$

For magnesium chloride the cost is

$$\$0.80/\text{gal} \times 0.2 \text{ gal m.c./gal. diluted sol} \times 0.5 \text{ gal/yd}^2 \times 1.1947 \text{ yd}^2/\text{m}^2 = \$0.10/\text{m}^2$$

Except for MC-70, which has to be applied hot, the preceding fixatives could be applied by either a distributor tank truck or water spray truck or by aircraft. A distributor tank truck would be preferable in that it is capable of applying a more uniform coating. Much information on the costs and rates of application of liquids was presented earlier in this appendix, so it will not be necessary to repeat those calculations in detail. (See Sections A.1.3 and A.1.5.)

The representative fixative cost used here is based on a single treatment of Coherex at a ratio of one part Coherex to five parts water applied at 0.75 gallon per square yard. The resulting material cost is $0.19 per square meter, including shipping. Application is with the same inputs as described in Section A.5.3. Here, because of rougher terrain and greater distance to refilling location, we assume an average coverage rate 75% of that used for applying fixative to agricultural fields (Section A.5.3), 2192 square meters per hour.

Dividing the hourly costs of labor and equipment by the coverage rate yields the costs in terms of area:

$$\text{Labor:} \quad \frac{\$19.75/\text{hr}}{2192\ \text{m}^2/\text{hr}} = \$0.0090/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$27.37/\text{hr}}{2192\ \text{m}^2/\text{hr}} = \$0.0125/\text{m}^2$$

Adding the input costs gives the total cost per square meter as $0.2115.

A.7.2 Clear

Clearing vacant land of brush and small trees will remove radioactive particles that adhere to the removed material. In addition, clearing may be necessary before other operations such as scraping, fixing, or watering can be performed. Even if these operations could be done without clearing, their effectiveness would be increased by clearing.

The costs and rate for this operation are based on data presented in Means' Building Construction Cost Data 1982 (p. 24). This source specifies one common laborer with brush saw and rake to clear 565 square yards per day. Converting to square meters per hour and adjusting for one hour per shift for personnel and equipment decontamination gives a rate of

$$565\ \text{yd}^2/\text{day} \div 8\ \text{hrs/day} \times 0.836\ \text{m}^2/\text{yd}^2 \times 7/8\ \text{adj} = 52\ \text{m}^2/\text{hr}$$

The hourly cost of labor is $17.45. Dividing by the hourly coverage rate gives a labor cost of $0.34 per square meter.

A 35-horsepower gas-powered brush chipper with a six-inch cutter head is reported (p. 8) as having an hourly operation cost of $2.80. The monthly rental rate is $975. At 168 hours per month, rental comes to $5.80 per hour. The total equipment cost is, therefore, $2.80 + $5.80 = $8.60. In terms of dollars per square meter, the cost is $8.60 ÷ 52 m^2/hr = $0.17.

The total comes to $0.34 + $0.17 = $0.51 per square meter.

A.7.3 Scrape

The essential aspects of soil scraping are described in Section A.5.5. Here we assume the same hourly costs for the inputs to scrape soil on vacant land as on agricultural fields (Section A.5.5). However, because of less even terrain and harder soil, we assume the average surface coverage rate for vacant land to be 75% of that for agricultural fields. The resulting coverage rate is 656 square meters per hour.

The input costs per square meter are easily calculated:

Labor: $\frac{\$116.50/\text{hr}}{656\ \text{m}^2/\text{hr}} = \$0.18/\text{m}^2$

Equipment: $\frac{\$152.92/\text{hr}}{656\ \text{m}^2/\text{hr}} = \$0.23/\text{m}^2$

The total cost is \$0.41 per square meter. The cost of hauling the soil away is calculated separately and is primarily a function of the distance to the dump site.

A.7.4 Water

The basic aspects of water application are described in Sections A.1.2 and A.4.2. The equipment used would be the tank distributor truck arrangement described in Section A.1.3.

Here we assume that the vehicle is able to maintain the same speed while spraying as used in Section A.1.3--one mile per hour. However, because of greater distance to water supply locations, we use a refill time of one hour. The result is an average coverage per shift-hour of

$$\frac{1\ \text{mi/hr} \times 5/6\ \text{hr spray} \times 5280\ \text{ft/mi} \times 10\ \text{ft wide} \times 0.0929\ \text{m}^2/\text{ft}^2 \times 7/8\ \text{adj}}{(5/6\ \text{hr spray} + 1\ \text{hr refill})}$$

$$= 1951\ \text{m}^2/\text{hr}$$

Using the same hourly labor and equipment costs, the input costs on a square-meter basis are calculated as follows:

Labor: $\frac{\$19.75/\text{hr}}{1951\ \text{m}^2/\text{hr}} = \$0.010/\text{m}^2$

Equipment: $\frac{\$27.37/\text{hr}}{1951\ \text{m}^2/\text{hr}} = \$0.014/\text{m}^2$

The total cost per square meter is \$0.024.

A.7.5 Leach

The basic aspects of leaching as a decontamination operation are described in Section A.4.3. For leaching vacant land, a 5000-gallon tank distributor truck with spray bar would be used. This equipment is described in Sections A.1.3 and A.5.2. In order to apply 0.3 inch of water, the vehicle's speed would need to be reduced from one mile per hour, as used in Section A.1.3 and in the previous section, A.7.4, to 0.6 mile per hour. In addition, we assume that increased distance to water supplies would raise the refill time to one hour. The net result of this is that the adjusted hourly coverage rate is 0.6 times the rate given in Section A.7.4.

$$\frac{0.6\text{ mi/hr} \times 5/6\text{ hr spray} \times 5280\text{ ft/mi} \times 10\text{ ft wide} \times 0.0929\text{ m}^2/\text{ft}^2 \times 7/8\text{ adj}}{(5/6\text{ hr spray} + 1\text{ hr refill})}$$

$$= 0.6 \times 1951\text{ m}^2/\text{hr}$$

$$= 1171\text{ m}^2/\text{hr}$$

With the same hourly labor and equipment costs, the costs per unit area are:

Labor: $\dfrac{\$19.75/\text{hr}}{1171\text{ m}^2/\text{hr}} = \$0.017/\text{m}^2$

Equipment: $\dfrac{\$27.37/\text{hr}}{1171\text{ m}^2/\text{hr}} = \$0.023/\text{m}^2$

The material cost per square meter is calculated in Section A.4.3 as \$0.026. The total cost per square meter is \$0.066.

A.7.6 Plow

Section A.5.6 describes plowing as a decontamination operation for agricultural fields. Where the soil is not too hard, plowing of vacant land can also be done. Where soil conditions warrant, a bulldozer with ripper shanks can be used in place of a normal wheel-mounted farm tractor.

Primary sources for this operation include various Cooperative Extension publications. "Almond Establishment Costs on Class II and Class III Soils in Sacramento Valley," published by the University of California Cooperative Extension, lists the cost of land preparation at $100 per acre. A similar University Cooperative Extension publication, "Costs to Establish English Walnut Orchard in Sacramento Valley," estimates land preparation costs at $50 per acre. Such land preparation involves shallow subsoil and discing, according to "Costs of Establishing and Producing Prunes," also published by the University of California Cooperative Extension. Subsoil and discing are described in Sections A.5.6 and A.5.7.

Based on these publications and another from the same organization, "Orchard Development Costs," we estimate the cost per acre at $100. With adjustment for one hour per shift for personnel and equipment decontamination, the cost per square meter is

$$\$100/\text{ac} \div 4046.7\ \text{m}^2/\text{ac} \times 8/7\ \text{adj} = \$0.028$$

In addition, we assume that the hourly cost of plowing vacant land will be somewhat higher than that for plowing agricultural fields. This is because, on average, heavier equipment will be necessary, more fuel will be required, and an operator of higher skill may also be necessary. The hourly cost used here is $50, compared with $34 for plowing agricultural fields. The implied coverage rate is

$$\$50/\text{hr} \div \$0.028/\text{m}^2 = 1770\ \text{m}^2/\text{hr}$$

Assuming the same cost shares for labor (25%), equipment (55%), and fuel (20%) as in plowing, the various input costs are:

Labor: $\$0.007/\text{m}^2$

Equipment: $\$0.015/\text{m}^2$

Fuel: $\$0.006/\text{m}^2$

A.7.7 Deep Plow

Deep plowing is described in Section A.5.7. That section also describes the data available for this operation. For deep plowing agricultural fields, the representative cost is estimated at $0.06 per square meter. The cost for deep plowing vacant land will, of course, be greater. Agristruction advises that their cost per acre for deep plowing hard soil is $500 per acre. This is equivalent to $0.12 per square meter. However, Agristruction's costs tend to be higher than those provided by most other sources. This is apparently due to deeper plowing and harder soils plowed by Agristruction. Based on this figure, we estimate a cost of $0.10 per square meter. Also, we estimate a higher hourly cost due to greater equipment wear, greater fuel use, and the possible need for heavier equipment. The hourly cost of $400 for deep plowing vacant land compares with $300 for deep plowing agricultural fields. The implied coverage rate is $\$400/\text{hr} \div \$0.10/\text{m}^2 = 4000\ \text{m}^2/\text{hr}$. This rate is higher than the normal plowing rate (Section A.7.6) because much more powerful equipment is used.

The equipment operator will cost about $25 per hour according to Means' Building Construction Cost Data 1982 and Agristruction. This comes to $0.006 per square meter. The remaining cost, $0.094 per square meter, is for equipment.

A.7.8 Cover

See Section A.5.9 for a description of this operation and an explanation of the cost rate estimates.

A.8 WOODED AREA

A.8.1 Fixative

Fixatives are discussed in some detail in Section A.7.1. In addition, the problems of treating all surfaces of trees and ground were indicated in Section A.2.3 dealing with aerial application of fixative to orchards.

An appropriate choice of fixative appears to be lignosite. Here we temporarily assume an application rate of about 0.4 gallon per square yard of a 75% solution. The material cost for this mixture would be about $0.05 per square meter.

The most effective way to apply a fixative to a wooded area is by airplane. In fact, this method of application is appropriate for most any exterior surfaces, if the area is sufficiently large. This could be done using aircraft that spray crops, or the larger planes that dump water and fire retardant on forest fires appears to be practical. Large scale water drops used in fighting forest fires generally spread a load of 3,000 gallons over an area of from 40,000 to 80,000 square feet. This is equal to about 0.45 gallons per square yard - slightly more than called for. Dumping the fixative while flying at a greater speed, dumping the oil at a slower rate, or possibly dumping from a higher altitude would have the effect of spreading the material out more thinly over a larger area. A buildup of multiple thin layers of fixative should assure a fairly even application, though there is some uncertainty in this respect.

One cost estimate for aerial application came from the U.S. Forest Service in Portland, Oregon. They reported a cost of about $1.00 per gallon. However, this included the cost of fire retardant and other expenses involved in this fire fighting operation. Aerial application comprised about half these costs, or $0.50 per gallon. At a coverage rate of 0.4 gallons per square yard, this is equivalent to $0.24 per square meter.

A company with which that Forest Service office contracts for aerial fire fighting operations is Butler Aviation in Redmond, Oregon. The figures supplied by Butler Aviation implied a cost as low as $0.23 per gallon or $0.11 per square meter. The considerable difference between these two cost estimates is surprising, especially since the two sources are involved in the same transaction. The difference appears to result from the way in which the service is contracted. Butler Aviation charges $1000 per day per plane and $2000 per flying hour per plane. The charges, being time-based, will result in a lower cost per gallon when more gallons per hour are dumped. The Forest Service's figures appear to be based on costs realized in actual operation. To the extent that Forest Service fire-fighting operations do not always involve continuous 24-hour, high-rate dumping, their costs per gallon will be higher than the possible minimum.

Butler Aviation's cost per gallon was calculated on the following basis. The capacity per plane is 3,000 gallons. The maximum dump rate is four loads per hour. This can be attained when the dump site is near the landing site. Decontamination operations would provide a situation in which it is likely that a fairly high and steady rate of operation could be maintained. An airbase for these operations close to the dump site will probably be available. On the other hand, the necessity of applying fairly thin coats will slow the application rate somewhat. Therefore, a rate of three dumps per hour was assumed. Further, one hour in eight is assumed necessary for radiation decontamination treatment of equipment. Therefore, over a 24-hour period, there will be 21 hours of dumping. At 3 dumps per hour and 3,000 gallons per dump, 189,000 gallons will be dumped in 24 hours. The cost for this will be the $1,000 daily charge plus 21 times the $2,000 hourly charge. This will bring the total aircraft costs over a 24-hour period to $43,000. This is equivalent to $0.2275 per gallon or $0.1088 per square meter for aerial application. Over a 24-hour period the gallonage would be enough for 395,071 square meters, or 16,461 square meters per hour.

Near the higher of these two cost figures were the rates charged by Columbia Aerial Ag Service of Pasco, Washington. To a commercial agricultural spray company, such as this one, the coverage of 0.4 gallons per square yard is considerably more than the 3 to 10 gallons per acre coverage to which they are accustomed--about 200 times more. Their charges are geared to the particular chemical and the coverage specified by the farmer. Converting their charges into a cost per gallon or a cost per square meter requires a generous use of estimates and assumptions. According to Columbia Ag Service, their charges are roughly equivalent to $400 to $500 per tachometer-hour and they generally run one tachometer-hour every 1.25 clock hours. Average operating speed is 100 miles per hour. It normally takes 60 seconds to dump a load of 350 gallons, and five minutes is required for refilling the aircraft. In addition to the estimated flying time, 25 percent for "maneuvering" needs to be included. Assuming a target site 10 miles from the aerial operations base, the following is implied:

time to dump site	6 min
time for dump	1 min
time for return	6 min
time for maneuvering	3.25 min
total flight time	16.25 min

In addition:

time for reloading plane	5 min

This gives:

total time for 350-gallon dump	21.25 min

These figures are roughly consistent with the ratio of one tachometer-hour to 1.25 clock hours. At the rate of $500 per tachometer-hour, the cost per dump is:

$$\frac{16.25 \text{ min/dump}}{60 \text{ min/hr}} \times \$500/\text{hr} = \$135.42/\text{dump}$$

The cost of aerial application per gallon is, then,

$$\frac{\$135.4167}{350 \text{ gal}} = \$0.3869/\text{gal}$$

Since these costs are based on tachometer-hours, no adjustment is necessary to account for one hour per shift for equipment decontamination. The application cost per square meter is:

$$\$0.3869/\text{gal} \times 0.4 \text{ gal/yd}^2 \times 1.19599 \text{ yd}^2/\text{m}^2 = \$0.19/\text{m}^2$$

At 350 gallons every 21.25 minutes, the average hourly dump rate is 988 gallons. Adjusting for seven operating hours per eight-hour shift, the hourly rate is 864 gallons or 1808 m^2/hr.

While Carr Aviation of Pasco, Washington, was not able to supply as much detailed information as other aviation companies, they did supply their basic price schedule which can be converted to a dollar-per-gallon basis.

TABLE A.8.1.1. Charges for Aerial Application by Carr Aviation

Coverage (gal/acre)	Cost (1982 $)	$/gal
3	3.60	1.2000
5	4.40	0.8800
8	4.90	0.6125
10	5.40	0.5400

These prices do not include the cost of the chemicals. Further, since these prices are based on the cost of application per gallon rather than per hour, no adjustment for seven hours output per eight-hour shift is necessary.

The declining cost per gallon with increased coverage suggests that a very rough estimate of $0.50 per gallon for very large volumes would not be too low. It is quite possible that lower rates would be charged. At $0.50 per gallon, or $0.24 per square meter, these were the highest cost estimates for aerial application obtained. The information supplied by Carr Aviation was insufficient to estimate the rate of treatment.

Table A.8.1.2 summarizes the aerial-application costs on a per-gallon basis. The representative cost is taken as $0.32 per gallon, which is lower than the average of the separate cost estimates. The reason for this is that application with the large-capacity planes used for fire fighting is more likely than with the smaller and higher per-gallon cost aircraft. Further, as explained earlier, the cost figures supplied by the Forest Service are for non-continuous operation and are therefore probably higher than would be the case in the event of continuous application of a fixative.

TABLE A.8.1.2. Summary of Aerial Application Cost Estimates by Source

Source	Cost (1982 $/gal)
U.S. Forest Service	0.50
Butler Aviation	0.23
Columbia Ag Service	0.39
Carr Aviation	0.50
Representative	0.32

Table A.8.1.3 presents costs on a per-square-meter basis. Also included is the cost of the fixative. These costs are based on a fixative application rate of 0.4 gallon per square yard. Different application rates would imply different costs.

TABLE A.8.1.3. Summary of Aerial Application of Fixative Cost Data[(a)]

Source	Cost (1982 $/m^2)		
	Aer. App.	Fixative	Total
U.S. Forest Service	0.24	0.05	0.29
Butler Aviation	0.11	0.05	0.16
Columbia Ag Service	0.19	0.05	0.24
Carr Aviation	0.24	0.05	0.29
Representative	0.15	0.05	0.20

(a) Based on 0.4 gallon of fixative per square yard.

Estimates for the rate of surface treatment ranged from Columbia Ag Service's rate of 1808 square meters per hour to the Butler Aviation high-volume rate of 16,461 square meters per hour. Since the larger aircraft is more likely to be used, we take 14,000 square meters (6690 gallons) per hour as a representative application rate. A cost of $0.15 per square meter for the cost of application is taken as representative, bringing the total cost with the fixative to $0.20 per square meter.

The operations for decontaminating paved surfaces include vacuuming, flushing with water at various pressures, special chemical techniques, and road construction procedures. These are described in detail in this section.

The representative inputs include, for labor, one pilot, one flight crew, and two ground crews. The hourly cost of labor is estimated at $140 per hour. Equipment is one tanker airplane at $1960 per hour. The resulting costs per square meter are $0.01 for labor and $0.14 for equipment.

As mentioned earlier, this discussion has been premised on a standard application of lignosite - 0.4 gallon per square yard. However, tree foliage will greatly increase the total surface area for each square meter of ground. For this reason and because of the difficulty in achieving an even coating of fixative, a higher application rate will probably be necessary. If we assume one gallon of fixative per square yard, this will raise the costs by a factor of $1.0 \div 0.4 = 2.5$ and lower the rate to

$$14{,}000\ m^2/hr \div 2.5 = 5600\ m^2/hr$$

The total cost is $0.495 per square meter. The labor cost is $0.025 per square meter, and equipment and materials cost $0.350 and $0.120 per square meter, respectively. We take these costs to be representative of fixative application to wooded areas.

A.8.2 Defoliate

Defoliation as a decontamination technique is described in Section A.6.6. Wooded areas will likely require a heavier application than orchards. Here we assume that a 50% greater application of materials would be used. As a result, all input costs would be increased by 50%:

Labor:	$\$0.0006/m^2 \times 1.5 = \$0.0009/m^2$
Equipment:	$\$0.0015/m^2 \times 1.5 = \$0.0023/m^2$
Materials:	$\$0.0105/m^2 \times 1.5 = \$0.0158/m^2$
Fuel:	$\$0.0020/m^2 \times 1.5 = \$0.0030/m^2$

The total cost per square meter is $0.0220. The rate is reduced by one-third:

$$8331\ m^2 \times 0.667 = 5554\ m^2/hr$$

A.8.3 Clear

Clearing involves removing trees and bushes. The data for this operation come from Means' Building Construction Cost Data 1982 (p. 24). The labor specified for this operation and the hourly costs are:

1 Foreman @ \$22.25	\$ 22.25
4 Building laborers @ \$19.40	77.60
1 Medium-equipment operator @ \$24.95	24.95
Total labor	\$124.80

The equipment listed for clearing and the hourly costs are:

1 Chipping machine	\$ 16.11
1 Front-end loader	72.46
Total equipment	\$ 88.57

The rate is given by Means as 0.60 acres per day. Converting to square meters per hour and adjusting for one hour lost per shift for personnel and equipment decontamination, we get:

$$0.60 \text{ ac/day} \div 8 \text{ hrs/day} \times 4046.7 \text{ m}^2\text{/ac} \times 7/8 \text{ adj} = 266 \text{ m}^2\text{/hr}$$

Dividing the hourly coverage rate into the hourly costs gives the costs in terms of dollars per square meter:

Labor: $\frac{\$124.80/\text{hr}}{266 \text{ m}^2/\text{hr}} = \$0.469/\text{m}^2$

Equipment: $\frac{\$88.57/\text{hr}}{266 \text{ m}^2/\text{hr}} = \$0.333/\text{m}^2$

The total cost per square meter is \$0.802.

A.8.4 Grub and Scrape

The operation of clearing does not include removal of tree stumps, and as long as they remain, soil scraping using front-end loaders cannot be done effectively. Therefore, removing the stumps, a procedure called grubbing, is a prerequisite for mechanized scraping.

The source for grubbing is Means' Building Construction Cost Data 1982 (p. 24). The labor and the associated hourly labor costs for this activity are one medium-equipment operator and two heavy-truck drivers. Since the cost of hauling material is handled spearately in this work, we delete the two truck drivers along with the two dump trucks. The equipment for this procedure is one 1.5-cubic yard hydraulic excavator costing \$70.51 per hour.

The production rate is given as 1.20 acres per day. The following converts this figure to square meters per hour and adjusts for one hour per shift devoted to personnel and equipment decontamination:

$$1.20 \text{ ac/day} \div 8 \text{ hrs/day} \times 4046.7 \text{ m}^2\text{/ac} \times 7/8 \text{ adj} = 531 \text{ m}^2\text{/hr}$$

Dividing the hourly labor and equipment costs by the hourly coverage rate gives the costs in terms of dollars per square meter:

$$\text{Labor:} \quad \frac{\$24.95/\text{hr}}{531 \text{ m}^2/\text{hr}} = \$0.047/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$70.51/\text{hr}}{531 \text{ m}^2/\text{hr}} = \$0.133/\text{m}^2$$

$$\text{Total:} \quad \$0.047/\text{m}^2 + \$0.133/\text{m}^2 = \$0.18/\text{m}^2$$

The cost and rate for scraping are taken to be the same as for scraping vacant land. These costs are shown in Table A.8.4.1. This table also shows the total costs for the entire grub and scrape operation. Since scraping is the more costly procedure, the rate for the whole operation is set equal to the rate for that procedure. This requires that 656 ÷ 531 = 1.24 grubbing crews are required for every scraping crew.

TABLE A.8.4.1. Summary of Grub and Scrape Data for Wooded Areas

Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment
Grub	531	0.18	0.05	0.13
Scrape	656	0.41	0.18	0.23
Total	656	0.59	0.23	0.36

A.8.5 Manual Scrape

While use of earthmoving equipment for scraping is not feasible in wooded areas without first clearing and grubbing, scraping can be accomplished without clearing and grubbing if done manually. The inputs for this operation are simply a laborer plus minor hand equipment such as a shovel and a wheelbarrow. The hourly cost for a common laborer is \$17.45, and we estimate \$1.00 per hour to be sufficient to cover equipment.

The coverage rate will be highly variable, depending on such things as hardness of the soil, roughness of the terrain, and how far the soil has to be moved to dump trucks for disposal. Various rate estimates for hand excavation are given in Means' Building Construction Cost Data 1982 (pp. 29, 30). These figures vary from four to eight cubic yards per day for excavating pits or trenches. We assume a base rate of eight cubic yards per day. If the surface is scraped to a depth of six inches, then each cubic yard represents six square yards of area scraped. Eight cubic yards per day, with adjustment for an hour per shift for personnel decontamination, is equivalent to:

$$8\ yd^3/day \div 8\ hrs/day \times 6\ yd^2/yd^3 \times 0.836\ m^2/yd^2 \times 7/8\ adj$$
$$= 4\ m^2/hr$$

Dividing the hourly cost figures by the hourly coverage rate yields costs in terms of dollars per square meter:

Labor: $\dfrac{\$17.45/hr}{4\ m^2/hr} = \$4.36/m^2$

Equipment: $\dfrac{\$1.00/hr}{4\ m^2/hr} = \$0.25/m^2$

Total: $\$4.36/m^2 + \$0.25/m^2 = \$4.61/m^2$

A.8.6 Cover Scraped Land

Section A.5.9 discusses covering the ground with uncontaminated soil as a decontamination operation. If a wooded area has been cleared and grubbed, covering is essentially the same as it would be for vacant land. We use the same costs here. (See Section A.7.8.)

A.8.7 Cover Unscraped Land

Covering the ground with soil as a decontamination operation is described in Section A.5.9. This operation involves two basic steps, soil excavation and soil placement. The cost and rate of soil excavation are the same as those listed in Section A.5.9. Placement of soil by hand in a wooded area is essentially the reverse of manual scraping as described in Section A.8.5. We assume, however, that the placement rate is 50% faster than scraping. Table A.8.7.1 summarizes the cost data. The rate of the combined operation is set equal to that of the more costly suboperation, placement. This means that 6 ÷ 812 = 0.001 excavation crews would be needed for each placement crew.

TABLE A.8.7.1. Summary of Data for Covering Wooded Areas with Uncontaminated Soil Without Grubbing

Procedure	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment
Excavation	812	0.166	0.043	0.123
Placement	6	3.08	2.91	0.17
Total	6	3.24	2.95	0.29

A.9 EXTERIOR PAINTED WOOD WALLS

Exterior painted wood walls are representative of the exterior surface of the large part of residential structures as well as many commercial buildings.

A.9.1 Water Wash

This operation involves hosing the surface with water. The essentials of such a water wash operation are described in the discussions of similar operations in Sections A.1.2 and A.3.2. In this case no special equipment, such as pumps or special hoses to raise the water pressure or special nozzles, are required. Walls would be hosed using water from existing mains and plumbing. The labor required would be one common laborer whose hourly billing cost is estimated at $17.45 based on labor costs from Means publications. One dollar per hour should be adequate to cover equipment costs.

The cost per unit area depends on the coverage rate. We estimate a basic rate of 100 square feet in two minutes, but in addition, about 10 minutes per hour would be necessary for moving to new locations and attaching the hose. This implies a rate of 2500 square feet per hour. Converting to square meters and adjusting for one hour per shift for personnel and equipment decontamination, we get:

$$2500\ \text{ft}^2/\text{hr} \times 0.0929\ \text{m}^2/\text{ft}^2 \times 7/8\ \text{adj} = 203\ \text{m}^2/\text{hr}$$

Input costs on a dollars per square meter basis are found by division, as follows.

Labor: $$\frac{\$17.45/\text{hr}}{203\ \text{m}^2/\text{hr}} = \$0.086/\text{m}^2$$

Equipment: $$\frac{\$1.00/\text{hr}}{203\ \text{m}^2/\text{hr}} = \$0.005/\text{m}^2$$

The total cost is the sum of these two figures, $0.091 per square meter.

A.9.2 Wash and Scrub

Two sources provided information on costs and rates for washing and scrubbing walls. Northwest Janitorial Systems of Seattle, Washington, advised that they charged between $0.15 and $0.20 per square foot for wall cleaning. This cost applies to both interior and exterior walls. This source further indicated that the total hourly cost was about $15.00. These figures imply an adjusted production rate of about six to eight square meters per hour. We use a rate of six square meters per hour here. Assuming that labor comprises 80% of the costs, or $12.00 per hour, the labor cost comes to $1.72 per square meter. The equipment cost is $0.43 per square meter, and the total comes to $2.15 per square meter.

American Building Maintenance of Seattle, Washington, indicated both a higher rate (200 square feet per hour) and a higher hourly cost ($18.50 per hour). The adjusted coverage rate comes to 16 square meters per hour with a total cost of $1.14 per square meter. The labor cost is $0.69 per square meter, and equipment accounts for $0.45 per square meter.

Table A.9.2.1 summarizes this information and shows the representative cost and rate figures.

TABLE A.9.2.1. Summary of Data for Wash and Scrub of Walls

Source	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment
Northwest Janitorial Systems	6	2.15	1.72	0.43
American Building Maintenance	16	1.14	0.69	0.45
Representative	10	1.75	1.15	0.60

A.9.3 Fixative

A general discussion of fixatives is provided in Section A.7.1. For application to walls, Compound SP-301, with a cost of $0.23 per square meter, appears to be the best choice. Since this material can be applied in the same manner and with the same equipment as spray painting, the application cost is estimated on the basis of this activity.

The basic data source for fixatives is Means' Building Construction Cost Data 1982 (pp. 231, 236). The daily coverage rate is given as 4000 square feet. This converts to

$$4000 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} \times 0.0929 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ adj} = 40 \text{ m}^2/\text{hr}$$

The costs are listed as $22.55 per hour for an ordinary painter and $2.00 per hour for the spray equipment. Dividing by the hourly coverage rate gives $0.555 per square meter for labor and $0.049 per square meter for equipment. Adding the cost of the fixative brings the total cost per square meter to $0.834.

A.9.4 Vacuum

Vacuuming as a decontamination technique is described elsewhere in this Appendix (see Sections A.1.1 and A.3.1). The primary source for data regarding the vacuuming of walls is American Building Maintenance of Seattle, Washington. This source advised that the hourly cost for this type of procedure would be $18.50 per hour with about $11.14 for labor. The hourly coverage rate is between 800 and 900 square feet. This converts to an adjusted 69 square meters per hour.

Dividing the hourly cost figures by the hourly coverage rate yields costs per square meter: $0.16 for labor, $0.11 for equipment. The total is $0.27 per square meter.

A.9.5 Hydroblast

Hydroblasting uses a high-pressure water jet to scour surfaces. Power Master, Inc. of Seattle, Washington, utilizes two types of hydroblasting equipment for contract hydroblasting work. The type of equipment used depends on the nature of the job and the surface. One type puts out 30 gallons per minute at a maximum of 10,000 to 20,000 pounds per square inch. If the spray lance is kept moving, this will do minimal damage to the surface. However, there is a safety problem with this equipment. The considerable recoil on the lance makes it hard to hold, and the water jet could cut through a person.

The other unit is an ultra-high-pressure system, generating a water jet up to 55,000 pounds per square inch. However, since only 1.9 gallons per minute is expelled, there is little or no recoil, making the lance much easier to control. The lance can be operated with a rotating head that keeps the jet moving around in a six-inch diameter circle. This reduces the risk of boring a hole through the surface being blasted and permits cleaning with a six-inch wide swath.

Since either equipment can be operated at lower pressures appropriate for surfaces such as wood, the costs for the second system are used here as representative for hydroblasting. The basic charge is $96 per hour, including the operator. However, more than one lance can be operated with each of the 475-horsepower truck-mounted V-12 pumps. There is an additional charge of $44 per hour per lance, up to a maximum of five. The calculations here are based on a cost of $70 per hour per lance, which is consistent with two lances per truck.

The coverage rate per lance for this system is reported at about 20 feet by 20 feet in two hours. This comes to about 11 square meters per hour with adjustment for personnel and equipment decontamination.

The labor cost is $16.50 per hour, and the equipment cost (per lance) is $53.50. Dividing by the hourly coverage rate gives the labor cost as $1.55 per square meter and the equipment cost as $5.00 per square meter.

To this we add the cost of one common laborer at $17.45 per hour with a wet vacuum costing $1.00 per hour. The resulting total cost is $8.50 per square meter, of which $3.39 is for labor and $5.11 is for equipment.

A.9.6 High-Pressure Water

This operation uses equipment frequently employed to strip old paint from wood walls. A small portable pump is used to raise the water pressure. In addition, there is a spray wand with special nozzle for directing the water to the surface. The cost for this equipment, based on rental information supplied by Handy Andy Rent-A-Tool in Seattle, Washington, is $600 per month. This comes to about $2.00 per hour.

The labor required is one common laborer at $17.45 per hour.

The coverage rate for this equipment was observed at about 90 square feet per hour for a thorough job of paint removal. With adjustment for one hour per shift for personnel and equipment decontamination, this is equivalent to 8 square meters per hour.

Dividing the coverage rate into the hourly costs gives $2.18 per square meter for labor, $0.25 for equipment, and $2.43 for the total.

A.9.7 Remove and Replace

For severely contaminated exterior painted wood walls, it may be necessary to remove and replace the entire surface. Normally this would be preceded by vacuuming and application of a fixative.

Removal and replacement involves three distinct steps for which costs and rates are estimated separately. These are removal of existing wall surfaces, replacement with new siding, and painting of new siding. The primary source for this operation is Means' Building Construction Cost Data 1982. This source provides mutually consistent data for all three procedures.

Exterior wood wall removal, according to Means (p. 371), requires one foreman at $22.25 per hour and two building laborers at $19.40 per hour each, for a total hourly labor cost of $61.05. Equipment would be those tools normally supplied by the workers themselves.

The production rate given is 700 square feet per day. After adjusting for one hour per shift for personnel decontamination, this rate converts to 7 square meters per hour. Dividing this into the hourly cost gives $8.60 per square meter, all of which is for labor.

According to Means (p. 162), replacement requires two carpenters at $24.35 per hour each. The total hourly labor cost is, therefore, $48.70. The hourly cost for power tools is given as $1.73. The total labor and equipment cost comes to $50.43.

The total hourly cost can be found by multiplying the hourly rate

$$750 \text{ ft}^2/\text{day} \div 8 = 93.75 \text{ ft}^2/\text{hr}$$

by the cost per square foot

$$93.75 \text{ ft}^2/\text{hr} \times \$0.89/\text{ft}^2 = \$83.43/\text{hr}$$

Subtracting the hourly labor and equipment charge from this total gives the hourly cost of materials:

$$\$83.43 - \$50.43 = \$33.00$$

The cost of materials is calculated as the difference between total and the sum of labor and equipment because Means reports total, labor, and equipment costs with markups for overhead. While overhead is implicitly added to material cost, the source does not provide information for direct calculation of the markup to be applied to materials. This calculation method yields the appropriate cost for materials with markup. The Means data requires this method be used in most every instance in which materials are part of the cost.

The hourly rate is

$$750 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} \times 0.0929 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ adj} = 7.6 \text{ m}^2/\text{hr}$$

Dividing this rate into the hourly input costs yields costs on a square-meter basis:

$$\text{Labor:} \quad \frac{\$48.70/\text{hr}}{7.6 \text{ m}^2/\text{hr}} = \$6.41/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$1.73/\text{hr}}{7.6 \text{ m}^2/\text{hr}} = \$0.23/\text{m}^2$$

$$\text{Materials:} \quad \frac{\$33.00/\text{hr}}{7.6 \text{ m}^2/\text{hr}} = \$4.34/\text{m}^2$$

The sum of these gives the total cost per square meter as $10.98.

Means (p. 231) indicates that painting wood siding with primer and one coat, including puttying, requires one ordinary painter at $22.55 per hour. The total cost per hour is found by multiplying the hourly rate

$$665 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} = 83.125 \text{ ft}^2/\text{hr}$$

by the cost per square foot

$$83.125 \text{ ft}^2 \times \$0.39/\text{ft}^2 = \$32.42/\text{hr}$$

The material cost is found by subtracting the labor cost from this total:

$$\$32.42/\text{hr} - \$22.55/\text{hr} = \$9.87/\text{hr}$$

The adjusted hourly coverage rate in metric units is

$$83.125 \text{ ft}^2/\text{hr} \times 0.0929 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ adj} = 6.8 \text{ m}^2/\text{hr}$$

Dividing the hourly costs by the hourly production yields the costs in terms of dollars per square meter:

$$\text{Labor:} \quad \frac{\$22.55/\text{hr}}{6.8\ \text{m}^2/\text{hr}} = \$3.32/\text{m}^2$$

$$\text{Material:} \quad \frac{\$9.87/\text{hr}}{6.8\ \text{m}^2/\text{hr}} = \$1.45/\text{m}^2$$

The total is the sum of the input costs, or $4.77 per square meter.

Table A.9.7.1 summarizes the foregoing calculations and shows the total costs for the entire operation combining the three steps. Using the convention employed throughout this report, the most costly procedure determines the overall rate. Therefore, the rate for the entire operation is 7.6 square meters per hour. This means that 7.6 ÷ 7.1 = 1.07 removal crews and 7.6 ÷ 6.8 = 1.12 painting crews would be used for every replacement crew. Together, in these ratios, they comprise an entire removal and replacement crew.

TABLE A.9.7.1. Summary of Data for Removal and Replacement of Painted Wood Exterior Walls

Procedure	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Materials
Removal	7.1	8.60	8.60	--	--
Replacement	7.6	10.98	6.41	0.23	4.34
Painting	6.8	4.77	3.32	--	1.45
Total	7.6	24.35	18.33	0.23	5.79

A.9.8 Remove Structure

In most severe cases it may be necessary to remove entire structures rather than attempt extensive decontamination operations. It should be noted that structure removal preempts any subsequent operation on any of the structure surfaces.

The primary information source for this operation is Means' Building Construction Cost Data 1982 (p. 372). However, the reported figures include allowance for hauling away of materials. Since hauling costs are estimated separately in this report, they must be deleted from the Means data. Excluding the specified heavy-truck driver and the dump truck, the specified labor requirements are one foreman at $22.22 per hour and two building laborers at $19.40 per hour each. The total hourly labor cost is $61.02. The only equipment specified are hand tools provided by the workers themselves.

The coverage rate is given at 360 square feet of floor area per day. This converts to

$$360\ \text{ft}^2/\text{day} \div 8\ \text{hrs/day} \times 0.0929\ \text{m}^2/\text{ft}^2 \times 7/8\ \text{adj} = 3.7\ \text{m}^2/\text{hr}$$

However, we wish to express the production rate in terms of exterior wall area. What is necessary is the ratio of exterior wall area to floor area. This can be estimated using residential factors used in Subroutine XFORM (see Appendix E). Factor h is the ratio of exterior wall area to roof area, and factor k is the ratio of floor area to roof area. Dividing h by k

$$h/k = 1.58/1.33 = 1.19$$

gives the ratio of exterior wall area to floor area. Therefore, the estimated hourly production rate is

$$3.7 \text{ m}^2/\text{hr} \times 1.19 = 4.4 \text{ m}^2/\text{hr}$$

Dividing the hourly costs by the hourly production rate yields the cost in terms of square meters of exterior wall area:

$$\text{Total} = \text{Labor: } \frac{\$61.02/\text{hr}}{4.4 \text{ m}^2/\text{hr}} = \$13.87/\text{hr}$$

A.9.9 Foam

The use of acidic foam as a decontamination operation is described in Section A.1.5. Also, the material cost is calculated there as $0.0753 per square meter for application and $0.0074 for removal, for a total material cost of $0.0827 per square meter.

Since the foam is applied with aspirated spray equipment as is paint, the application cost is taken as equal to the cost of applying a fixative to walls, which was estimated in Section A.9.3. Similarly, removal of the foam would be accomplished by vacuuming, the cost of which was developed in Section A.9.4.

Table A.9.9.1 summarizes these data and calculates the total costs for a foam treatment. Note that since the most costly procedure by convention determines the rate, 40 ÷ 69 = 0.58 removal crews would be combined with each application crew to make one foam treatment crew. The rate for the whole operation is 40 square meters per hour.

TABLE A.9.9.1. Summary of Data for Foam Treatment of Painted Exterior Wood Walls

Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
Application	40	0.6793	0.555	0.049	0.0753
Removal	69	0.2774	0.16	0.11	0.0074
Total	40	0.9567	0.715	0.159	0.0827

A.9.10 Strippable Coating

The basic functioning of strippable coating as a decontamination technique is described in Section A.1.6. In addition, the material cost was also calculated there at \$1.77 per square meter.

Like foam and fixative application to exterior painted wood walls (see Sections A.9.3 and A.9.9), strippable coating would be sprayed on. However, this material requires an airless sprayer. Here, as in the previous section, we use cost figures developed in Section A.9.3 for the application cost.

Removal costs and rates require extensive estimation since this is not an activity for which there is much data. Removal would involve one common laborer at \$17.45 per hour, equipped with incidental hand tools. We estimate the removal rate at 35 square meters per hour. The cost per square meter, therefore, is

$$\$17.45/hr \div 3\ m^2/hr = \$0.50/m^2$$

In addition to application and removal, there is also the cost of disposal of the removed coating. This is discussed in Section A.3.5, and the cost estimates used there for centralized collection of the coating are used here. Ultimate disposal costs are calculated as separate hauling costs.

The costs and rates are presented and summarized in Table A.9.10.1. The overall rate is set equal to that of the most costly step, application. This

TABLE A.9.10.1. Summary of Data for Strippable Coating Treatment of Painted Exterior Wood Walls

Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Application	40	2.37	0.55	0.05	1.77
Removal	35	0.50	0.50		
Collection	488	0.05	0.04	0.01	
Total	40	2.92	1.09	0.06	1.77

means that $40 \div 35 = 1.14$ removal crews and $40 \div 488 = 0.08$ collection crews would be combined with one application crew to form a complete crew for a strippable coating treatment.

A.10 EXTERIOR BRICK WALLS

Many decontamination operations for painted wood exterior walls are identical to operations applicable to brick walls. However, while operation costs and rates may be the same, the rougher texture and porosity of brick result in lower decontamination efficiencies.

A.10.1 Water Wash

See Section A.9.1.

A.10.2 Wash and Scrub

See Section A.9.2.

A.10.3 Fixative

See Section A.9.3.

A.10.4 Vacuum

See Section A.9.4.

A.10.5 Hydroblast

See Section A.9.5. Note that higher water pressures could be used on brick than on wood.

A.10.6 High-Pressure Water

See Section A.9.6.

A.10.7 Scarify

See Sections A.16.7 and A.14.8.

A.10.8 Remove and Replace

The general aspects of removing and replacing exterior walls are discussed in Section A.9.7. As in the case of removing and replacing exterior wood walls, Means' Building Construction Cost Data 1982 is the primary source of information.

Costs for the first step, wall removal, are estimated using Means data for concrete wall removal (p. 371) since no data are supplied for removal of brick walls. The labor specified is one foreman at $22.25 per hour and four building laborers at $19.40 per hour each. The total hourly labor cost comes to $99.85

For equipment, Means calls for an air compressor with air tools and accessories. These cost $18.00 per hour.

The rate for removing walls four to twelve inches thick is 220 cubic feet per day. Assuming an average wall thickness of eight inches, converting to metric units per hour and adjusting for one hour per shift for personnel and equipment decontamination yields a rate of 3.35 square meters per hour.

Dividing the hourly rate into the hourly costs results in costs per square meter:

Labor: $\dfrac{\$99.85/\text{hr}}{3.35\ \text{m}^2/\text{hr}} = \$29.81/\text{m}^2$

Equipment: $\dfrac{\$18.00/\text{hr}}{3.35\ \text{m}^2/\text{hr}} = \$5.37/\text{m}^2$

Total removal cost is

$\$29.81/\text{m}^2 + \$5.37/\text{m}^2 = \$35.18/\text{m}^2$

According to Means (pp. 114, 123), installing an eight-inch thick brick wall requires three bricklayers at \$24.85 per hour each, two bricklayer helpers at \$19.65 per hour each, and 0.25 carpenters for scaffolding construction at \$24.35 per hour each. The total hourly labor cost totals \$119.94.

The hourly material cost is found by subtracting the hourly labor cost from the hourly total cost:

$\$176.62/\text{hr} - \$119.94/\text{hr} = \$56.68/\text{hr}$

The rate in terms of square meters per hour is calculated in a straightforward manner based on 13.50 bricks per square foot. Along with adjustments, the rate is

$0.225\ \text{M br/hr} \times 1000\ \text{br/M} \div 13.50\ \text{br/ft}^2 \times 0.0929\ \text{m}^2/\text{ft}^2 \times 7/8\ \text{adj}$
$= 1.35\ \text{m}^2/\text{hr}$

Means' total cost per hour can be found by multiplying the number of thousand bricks (M) per hour by the total cost per thousand bricks laid. The daily output is listed at 1.8 thousand bricks. This comes to 0.225 thousand bricks per hour. The total cost per thousand bricks laid is \$785. Therefore, the cost per hour is

$0.225\ \text{M/hr} \times \$785/\text{M} = \$176.62/\text{hr}$

Dividing the hourly production rate into the hourly costs converts the costs to a dollars per square meter basis:

Labor: $\dfrac{\$119.94/\text{hr}}{1.35\ \text{m}^2/\text{hr}} = \$88.84/\text{m}^2$

Materials: $\dfrac{\$56.68/\text{hr}}{1.35\ \text{m}^2/\text{hr}} = \$41.99/\text{m}^2$

The total cost per square meter is the sum of these two costs, \$130.83 per square meter.

Table A.10.8.1 summarizes the preceding calculations and shows total costs per square meter for removal plus replacement. Since replacement is the more costly of the two constituent steps, its rate determines the rate of the overall combined operation. This means that 1.35 ÷ 3.35 = 0.40 removal crews would be used with one replacement crew to form the crew for the entire operation.

TABLE A.10.8.1. Summary of Data for Removal and Replacement of Exterior Brick Walls

Procedure	Rate (m^2/hr)	Cost (1982 $\$/m^2$)			
		Total	Labor	Equipment	Materials
Removal	3.35	35.18	29.81	5.37	--
Replacement	1.35	130.83	88.84	--	41.99
Total	1.35	166.01	118.65	5.37	41.99

A.10.9 Remove Structure

Structure removal is discussed in Section A.9.8. The difference in materials between buildings with exterior wood walls and those with brick walls has significant effect on costs and rates. Again, the basic data source is Means' Building Construction Cost Data 1982 (p. 372). In this case the maximum cost data for removal of a commercial structure are used.

The inputs for this operation are the same as discussed in Section A.9.8. Therefore, it is necessary to calculate the hourly production rate for building removal. Means lists a rate of 250 square feet of floor area per day. Again using factors from XFORM, but this time for commercial structures, we can estimate the ratio of exterior wall area to floor area:

$$h/k = 1.2/1.8 = 0.667$$

The hourly rate, adjusted and converted to metric units, is

$$250\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2 \times 7/8\ adj \times 0.667$$
$$= 1.69\ m^2/hr$$

Dividing by the hourly rate gives the costs per square meter. Labor is \$47.81 per square meter, equipment is \$21.14 per square meter, and the total is \$68.95 per square meter.

A.10.10 Foam

See Section A.9.9.

A.10.11 Strippable Coating

See Section A.9.10.

A.11 LINOLEUM FLOORS

This surface is intended to be representative of resilient floor coverings in general, including linoleum, asphalt tile, and vinyl. Many of the operations on this surface are similar or identical to operations on other interior floor surfaces and, in some cases, operations on wall surfaces.

A.11.1 Vacuum

Janitorial cleaning and painting sources indicated that the rates of operations on floors are not much different from the rates on walls. Therefore, the cost of this operation is taken to be the same as vacuuming painted wood exterior walls. See Section A.9.4.

A.11.2 Scrub and Wash

See Section A.9.2.

A.11.3 Strippable Coating

See Section A.9.10.

A.11.4 Foam

See Section A.9.9.

A.11.5 Fixative

See Section A.9.3.

A.11.6 Remove and Replace

In instances of severe contamination, removal and replacement of linoleum floor covering may be indicated. Data for this operation comes primarily from Means' Building Construction Cost Data 1982. The general range of these costs was supported by information from and discussion with sources at commercial floor covering businesses, including the Deluxe Carpet Company of Kent, Washington, and Long's Installations of Bellevue, Washington.

The crew specified for linoleum removal (p. 371) includes one foreman at \$22.25 per hour and four building laborers at \$19.40 per hour each. The total hourly labor cost comes to \$99.85. Equipment is just those hand tools supplied by the workers themselves.

The rate, listed as 2500 square feet per day, after adjustments is

$$2500\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 25\ m^2/hr$$

Dividing the hourly labor cost by the number of square meters per hour gives the labor cost as $4.00 per square meter.

According to Means (p. 228), labor for replacement of the linoleum flooring is one floor tile layer at $22.55 per hour.

Material costs range from about $0.50 per square foot for asphalt tile on concrete underlayment to over $5.50 per square foot for vinyl tile. Here we use a cost of about $0.60 per square foot or $6.36 per square meter.

The rate is given as 540 square feet per day. With adjustments, this is equivalent to

$$540 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} \times 0.0929 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ adj} = 5.48 \text{ m}^2/\text{hr}$$

Dividing this figure into the hourly labor cost yields a labor cost of $4.11 per square meter. Adding the material cost brings the total to $10.47 per square meter.

The foregoing is summarized in Table A.11.6.1, and the combined totals for the entire operation are presented. Note that 5.48 ÷ 25 = 0.22 removal crews would be used for each replacement crew.

TABLE A.11.6.1. Summary of Data for Removal and Replacement of Linoleum Floors

Procedure	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Materials
Removal	25	4.00	4.00	--	
Replacement	5.48	10.47	4.11	--	6.36
Total	5.48	14.47	8.11	--	6.36

A.12 WOOD FLOORS

See Section A.11.

A.12.1 Vacuum

See Sections A.9.4 and A.11.1.

A.12.2 Scrub and Wash

See Section A.9.2.

A.12.3 Strippable Coating

See Section A.9.10.

A.12.4 Foam

See Section A.9.9.

A.12.5 Sand

This operation involves sanding and refinishing the wood floor. Data come from Means' Building Construction Cost Data 1982 (p. 231). For our purposes, we use the maximum refinishing cost.

The labor required is one carpenter at $24.35 per hour. The total hourly cost is equal to the rate times the cost per square foot:

$$130\ ft^2/day \div 8\ hrs/day \times \$1.99/ft^2 = \$32.34/hr$$

Material cost can be found by subtracting the labor cost:

$$\$32.34/hr - \$24.35/hr = \$7.99/hr$$

This can be converted to cost per square meter by the following:

$$\$7.99/hr \div 16.25\ ft^2/hr \div 0.0929\ m^2/ft^2 = \$5.29/m^2$$

The adjusted rate for this operation is

$$130\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2 \times 7/8 = 1.32\ m^2/hr$$

Using this rate, the cost of labor per square meter can be found:

$$\$24.35/hr \div 1.32\ m^2/hr = \$18.45/m^2$$

Adding the labor and material costs gives the total cost:

$$\$18.45/m^2 + \$5.29/m^2 = \$23.74/m^2$$

A.12.6 Fixative

See Section A.9.3.

A.12.7 Remove and Replace

This operation has three distinct steps for which costs are calculated separately. They are removal, replacement, and finishing. The source for this operation is Means' Building Construction Cost Data 1982.

The removal crew specified (p. 371) includes one foreman at $22.25 per hour and four building laborers at $19.40 per hour each. The total labor cost comes to $99.85 per hour. The only equipment indicated would be small hand tools supplied by the workers themselves.

The adjusted rate is

$$1300\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 13.2\ m^2/hr$$

Dividing the hourly labor cost by the rate gives the labor (and total) cost as $7.50 per square meter.

For replacing a wood floor, Means advises a crew of one carpenter at $24.35 per hour. The total hourly cost is

$$170\ ft^2/day \div 8\ hrs/day \times \$3.37/ft^2 = \$71.61/hr$$

Subtracting the labor cost gives the hourly material cost:

$$\$71.61/hr - \$24.35/hr = \$47.26/hr$$

Converting this directly to cost per square meter is done as follows:

$$\frac{\$47.26/hr}{(170\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2)} = \$23.94/m^2$$

The adjusted rate is

$$170\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 1.73\ m^2/hr$$

Dividing this figure into the hourly labor cost gives

$$\$24.35/hr \div 1.73\ m^2/hr = \$14.08/m^2$$

Adding labor and material cost yields total cost:

$$\$14.08/m^2 + \$23.94/m^2 = \$38.02/m^2$$

For finishing a new floor, Means (p. 231) specifies the total cost as $0.99 per square foot and the daily production rate as 295 square feet. From these figures the total hourly cost is easily calculated:

$$295\ ft^2/day \div 8\ hrs/day \times \$0.99/ft^2 = \$36.50/hr$$

The labor required is one carpenter at $24.35 per hour. Subtracting the hourly labor cost from the hourly total cost gives

$$\$36.50/hr - \$24.35/hr = \$12.15/hr$$

for materials. This can be converted to a cost per square meter with the following calculations:

$$\frac{\$12.15/hr}{(295\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2)} = \$3.55/m^2$$

The adjusted rate is

$$295\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2 \times 7/8 = 3\ m^2/hr$$

Dividing the hourly labor cost by this figure gives the labor cost in dollars per square meter:

$$\$24.35/\text{hr} \div 3\ \text{m}^2/\text{hr} = \$8.12/\text{m}^2$$

Adding the labor and equipment costs yields the total cost:

$$\$8.12/\text{m}^2 + \$3.55/\text{m}^2 = \$11.67/\text{m}^2$$

The foregoing calculations are summarized in Table A.12.7.1. In addition, the costs for the entire combined operation are presented. The rate for the whole operation is set equal to that of the most costly procedure, following

TABLE A.12.7.1. Summary of Data for Removal and Replacement of Wood Floors

Procedure	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Removal	13.2	7.50	7.50	--	--
Replacement	1.73	38.02	14.08	--	23.94
Finish	3.00	11.67	8.12	--	3.55
Total	1.73	57.19	29.70	--	27.49

the convention used in this report. Consequently, 1.73 ÷ 13.2 = 0.13 removal crews and 1.73 ÷ 3.00 = 0.58 finishing crews would be combined with one replacement crew to form one crew for the entire operation.

A.13 CARPETED FLOORS

See Section A.11.

A.13.1 Vacuum

See Sections A.9.4 and A.11.1.

A.13.2 Foam

See Section A.9.9.

A.13.3 Fixative

See Section A.9.3.

A.13.4 Remove and Replace

The primary source of information for removal and replacement of carpet comes from Means' Building Construction Cost Data 1982. The general range of these figures was confirmed by information from and conversation with sources at Deluxe Carpet Company of Kent, Washington, and Long's Installations of Bellevue, Washington.

According to Means (p. 370), carpet removal requires one building laborer at \$19.40 per hour. The rate given is 100 square yards per day. With adjustments this implies a rate of

$$100\ \text{yd}^2/\text{day} \div 8\ \text{hrs/day} \times 0.836\ \text{m}^2/\text{yd}^2 \times 7/8\ \text{adj} = 9\ \text{m}^2/\text{hr}$$

Dividing this figure into the hourly cost gives \$2.12 per square meter.

According to the same source (p. 227), the total cost of carpet installation covers a range of from \$7.80 per square yard for 15-ounce polypropylene carpet to \$29.00 per square yard for 42-ounce sponge-backed wool carpet. The difference is due to different material costs. Here we assume a material cost of \$11.70 per square yard, or

$$\$11.70/\text{yd}^2 \times 1.196\ \text{m}^2/\text{yd}^2 = \$14.00/\text{m}^2$$

The rate for installation, with adjustments, is

$$40\ \text{yd}^2 \div 8\ \text{hrs/day} \times 0.836\ \text{m}^2/\text{yd}^2 \times 7/8\ \text{adj} = 3.7\ \text{m}^2/\text{hr}$$

Dividing this rate into the hourly cost for the one "tile layer, floor" required for carpet installation gives the labor cost per square meter:

$$\$22.55/\text{hr} \div 3.7\ \text{m}^2/\text{hr} = \$6.09/\text{m}^2$$

Adding the labor and material cost gives the total cost:

$$\$6.09/\text{m}^2 + \$14.00/\text{m}^2 = \$20.09/\text{m}^2$$

The results of the preceding calculations are presented in Table A.13.4.1. Also shown are the totals for the entire operation. Note that 3.7 ÷ 9 = 0.41 removal crews per replacement crew would be used in making up a

TABLE A.13.4.1. Summary of Data for Removal and Replacement of Carpet

Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Removal	9	2.12	2.12	--	--
Replacement	3.7	20.09	6.09	--	14.00
Total	3.7	22.21	8.21	--	14.00

single removal and replacement crew with a production rate of 3.7 square meters per hour.

A.13.5 Steam Clean

Data for steam cleaning carpets comes from Means' Building Construction Cost Data 1982 (p. 227). Two sets of costs and rates are given. The one with the slower rate and higher cost is used here. The total cost per hour can be found with the following calculations:

$$3250 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} \times \$0.06/\text{ft}^2 = \$24.38/\text{hr}$$

The specified labor is one building laborer at $19.40 per hour. Subtracting the labor cost from the total cost gives the equipment cost:

$$\$24.38/\text{hr} - \$19.40/\text{hr} = \$4.98/\text{hr}$$

With adjustments, the hourly rate is

$$3250 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} \times 0.0929 \text{ m}^2/\text{ft}^2 \times 7/8 = 33 \text{ m}^2/\text{hr}$$

Dividing this into the hourly input costs yields costs on a dollars per square meter basis:

$$\text{Labor:} \quad \frac{\$19.40/\text{hr}}{33 \text{ m}^2/\text{hr}} = \$0.59/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$4.98/\text{hr}}{33 \text{ m}^2/\text{hr}} = \$0.15/\text{m}^2$$

The total cost is the sum of the input costs, 0.74 per square meter.

A.13.6 Shampoo

Carpet shampooing involves applying the shampoo with a power brush device and vacuuming when the resulting foam has dried. Northwest Janitorial Systems of Mercer Island, Washington, estimates the cost of this operation at from $0.10 to $0.20 per square foot. A lower, but overlapping, range was provided by American Building Maintenance of Seattle, Washington, with their estimate of $0.05 to $0.11 per square foot. This source added that the hourly production rate was about 370 square feet and that labor comprised 60% of their cost.

Based on these figures and an assumed cost of $16.00 per hour each for two cleaning workers, this operation is estimated to have a rate of 40 square meters per hour and a total cost of $1.25 per square meter. Labor costs $0.80 per square meter, and equipment costs come to $0.45 per square meter.

A.14 CONCRETE FLOORS

See Section A.11.

A.14.1 Vacuum

See Sections A.9.4 and A.11.1.

A.14.2 Scrub and Wash

See Section A.9.2.

A.14.3 Strippable Coating

See Section A.9.10.

A.14.4 Foam

See Section A.9.9.

A.14.5 Scarify

In this report, scarification refers to any of a variety of methods to remove the surface of concrete floors, pavement, or walls. Information from three sources was combined to develop the cost and rate estimates of this operation. Two of these sources were associated with Concrete Coring Company. Their input specifications were combined with labor and equipment costs from Means' Building Construction Cost Data 1982.

Concrete Coring Company performs a wide range of jobs on concrete, including drilling, coring, flat sawing, flame cutting, grooving, and grinding. This company also has experience in working in radiation contaminated environments and in using remote-controlled equipment. According to a source in this company, the most effective means for treating concrete subjected to low contamination is with high-pressure water. For higher levels of contamination, the alternatives for surface treatment include grinding and saw cutting with chipping. The grinding procedure uses a rotating abrasive disk to grind away the surface. Water is used as a coolant and a dust suppressant. The other procedure has two basic steps. The first step is to cut grooves in the surface. In the second step, the high portions between the grooves are chipped away by hand. For both operations there are machines of various sizes, operating speeds, and operating costs. In general, grinding floors, roads, and other ground-cover surfaces is faster, easier, and less costly than grinding walls, ceilings, or sloped and irregular surfaces.

Based on input descriptions from Concrete Coring Company, costs are determined using data from Means, as shown in Table A.14.5.1.

To convert these hourly cost figures to a cost per square meter basis, it is necessary to estimate the production rate. Here, information is ambiguous. One source at Concrete Coring Company estimated a production rate of 2000 square feet per day. Another source with the same company estimated a rate of 96 square feet. The primary reason for this wide discrepancy is that the first source provided a rate estimate for normal operating conditions, while the second source adjusted the coverage rate to what it would be under severely contaminated conditions. The rate used here is between these two rates--800

TABLE A.14.5.1. Cost Data for Scarifying Concrete Surfaces

Labor	Cost (1982 $/hr)
1 Small-equipment operator @ $23.70/hr	23.70
2 Building laborers @ $19.40/hr	38.80
1 Foreman @ $22.25/hr	22.25
Total labor	84.75
Equipment	
1 Grinder	1.82
1 Wet vacuum	1.00
1 Pickup truck	5.42
Total equipment	8.24

square feet per day. Converted to square meters per hour and adjusted for one hour per shift lost to personnel and equipment decontamination, this comes to 8.1 square meters per hour.

Dividing the rate into the hourly costs gives $10.43 per square meter for labor and $1.01 per square meter for equipment. The total is $11.44 per square meter.

A.14.6 Resurface

This operation involves laying a thin layer of concrete over the existing concrete floor. The information for this operation comes from Means' Building Construction Cost Data 1982 (p. 83).

The labor designated includes one building laborer at $19.40 per hour and two cement finishers at $23.00 per hour each. The total hourly labor cost is $65.40. For equipment, two gas-powered cement finishing machines are specified for a total hourly charge of $6.85. The material cost comes to $8.88 per hour.

The coverage rate is 590 square feet per day. With adjustments, this comes to 6 square meters per hour. Dividing this into the hourly input costs yields:

Labor: $10.90/m^2

Equipment: $1.14/m^2

Materials: $1.30/m^2

Total: $13.34/m^2

A.14.7 High-Pressure Water

See Section A.9.6.

A.14.8 Hydroblast

See Section A.9.5.

A.14.9 Scarify and Resurface

This operation involves scarification as described in Section A.14.5, followed by resurfacing as described in Secton A.14.6. This information is summarized in Table A.14.9.1.

TABLE A.14.9.1. Summary of Data for Scarification and Resurfacing of Concrete Floors

Procedure	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Materials
Scarification	8.1	11.44	10.43	1.01	--
Resurfacing	6	13.34	10.90	1.14	1.30
Total	6	24.78	21.33	2.15	1.30

A.14.10 Fixative

See Section A.9.3.

A.15 PAINTED WOOD, PLASTER INTERIOR WALLS

Many of the operations on interior walls are similar or identical, with respect to costs and rates, to analogous operations on other wall or floor surfaces. Where this is the case, reference is made to the section in which development of cost and rate estimates is discussed. While costs and rates for a particular operation on different surfaces may be the same, decontamination efficiencies in general will not be.

A.15.1 Vacuum

See Section A.9.4.

A.15.2 Scrub and Wash

See Section A.9.2.

A.15.3 Strippable Coating

See Section A.9.10.

A.15.4 Foam

See Section A.9.9.

A.15.5 Fixative

See Section A.9.3.

A.15.6 Remove and Replace

The information for removal and replacement of interior painted wood, plaster walls comes from Means' Building Construction Cost Data 1982. This operation involves four separate steps: removal, replacement, tape and finishing, and painting.

According to this source (p. 371), removal requires one foreman at \$22.25 per hour and two building laborers at \$19.40 per hour each. The total hourly labor cost is \$61.05. The rate given for this procedure is 520 square feet per day, which converts to 5.28 square meters per hour. Dividing the labor cost by the rate yields a labor cost of \$11.56 per square meter.

Replacement (p. 219) requires two carpenters at \$24.35 per hour each. The total hourly cost is found by multiplying one-eighth the daily rate by the cost per unit:

$$1800 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} \times \$0.37/\text{ft}^2 = \$83.25/\text{hr}$$

Subtracting the labor cost gives the material cost:

$$\$83.25/\text{hr} - (2 \times \$24.35/\text{hr}) = \$34.55/\text{hr}$$

At 1800 square feet per day, the cost of materials is

$$\frac{\$34.55/\text{hr}}{(1800 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} \times 0.0929 \text{ m}^2/\text{ft}^2)} = \$1.65/\text{m}^2$$

The adjusted rate is

$$1800 \text{ ft}^2/\text{day} \div 8 \text{ hrs/day} \times 0.0929 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ adj} = 18 \text{ m}^2/\text{hr}$$

Dividing this into the hourly labor cost gives labor as \$2.66 per square meter. The total cost per square meter is the sum of labor and material:

$$\$2.66/\text{m}^2 + \$1.65/\text{m}^2 = \$4.31/\text{m}^2$$

The taping and finishing crew is again two carpenters. The total cost per hour is

$$2000\ ft^2/day \div 8\ hrs/day \times \$0.21/ft^2 = \$52.50/hr$$

Subtracting the labor cost gives the hourly material cost:

$$\$52.50/hr - (2 \times \$24.35/hr) = \$3.80/hr$$

This converts to

$$\frac{\$3.80/hr}{(2000\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2)} = \$0.16/m^2$$

The adjusted rate is

$$2000\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2 \times 7/8 = 20\ m^2/hr$$

Dividing this into the hourly labor cost yields

$$\$48.70/hr \div 20\ m^2/hr = \$2.40/m^2$$

Adding the labor and materials cost gives the total cost:

$$\$2.40/m^2 + \$0.16/m^2 = \$2.56/m^2$$

According to Means (p. 232), an ordinary painter has an hourly billing cost of $22.55 and a daily production of 490 square feet. The total hourly cost is

$$490\ ft^2/hr \div 8\ hrs/day \times \$0.45/hr = \$27.56/hr$$

Subtracting the labor cost gives the hourly material cost:

$$\$27.56/hr - \$22.55/hr = \$5.01/hr$$

This converts to

$$\frac{\$5.01/hr}{(490\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2)} = \$0.88/m^2$$

The adjusted hourly coverage rate is

$$490\ ft^2/day \div 8\ hrs/day \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 4.98\ m^2/hr$$

Dividing this into the hourly labor cost gives the labor cost as

$$\$22.55/hr \div 4.98\ m^2/hr = \$4.53/m^2$$

Adding labor and material costs gives the total cost per square meter:

$$\$4.53/m^2 + \$0.88/m^2 = \$5.41/m^2$$

Table A.15.6.1 summarizes the foregoing and shows the totals. Note that for a rate of 5.28 square meters per hour, 5.28 ÷ 18 = 0.29 replacement

TABLE A.15.6.1. Summary of Data for Removal and Replacement of Painted Wood, Plaster Walls

Procedure	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment	Material
Removal	5.28	11.58	11.56	--	--
Replacement	18.00	4.31	2.66	--	1.65
Taping and finishing	20	2.56	2.40	--	0.16
Painting	4.98	5.41	4.53	--	0.88
Total	5.28	23.84	21.15	--	2.69

crews, 5.28 ÷ 20 = 0.26 taping and finishing crews, and 5.28 ÷ 4.98 = 1.06 painting crews would be required.

A.16 INTERIOR CONCRETE WALLS

See Section A.15.0.

A.16.1 Vacuum

See Section A.9.4.

A.16.2 Scrub and Wash

See Section A.9.2.

A.16.3 Strippable Coating

See Section A.9.10.

A.16.4 Foam

See Section A.9.9.

A.16.5 Fixative

See Section A.9.3.

A.16.6 Scarify

See Section A.14.5. Means lists a lower cost for wall grinders, making the total hourly equipment cost \$7.42. More important, however, is the rate, which sources at Concrete Coring Company said would be lower for walls than for floors. Using a base rate of 50 square feet per hour, the adjusted rate comes to 4 square meters per hour. The total cost per square meter is \$22.68, of which \$20.85 is for labor and \$1.83 is for equipment.

A.16.7 High-Pressure Water

See Section A.9.6.

A.16.8 Hydroblast

See Section A.9.5.

A.16.9 Remove and Replace

The source for information regarding costs, rates, and inputs for removal and replacement of interior concrete walls is Means' Building Construction Cost Data 1982. Removal (p. 371) requires one foreman at $22.25 per hour and four building laborers at $19.40 per hour each. The total hourly labor cost comes to $99.85. Equipment is a 250 cubic feet per minute air compressor with air tools and accessories, costing $18.00 per hour.

The rate given by Means is 100 cubic feet per day. Assuming an average wall thickness of eight inches, the rate converts to

$$100 \text{ ft}^3/\text{day} \div 8 \text{ hrs/day} \times 1.5 \text{ ft}^2/\text{ft}^3 \times 0.0929 \text{ m}^2/\text{ft}^2$$
$$\times 7/8 \text{ adj} = 1.52 \text{ m}^2/\text{hr}$$

Dividing the rate into the hourly costs gives $65.51 per square meter for labor, $11.81 per square meter for equipment, and the total is $77.32 per square meter.

The labor specified for replacement (p. 82) includes two foremen at $27.85 each per hour and eight skilled workers at $25.00 per hour each. The total hourly labor cost is $255.70. The equipment specified include 0.125 80-ton cranes and power tools for an hourly cost of $14.93.

The listed rate is 9.6 cubic yards per day. For eight-inch thick walls this converts to 3.95 square meters per hour.

The hourly material cost is found by multiplying the hourly rate by the listed unit total cost and subtracting the other costs:

$$9.6 \text{ yd}^3/\text{day} \div 8 \text{ hrs/day} \times \$340/\text{yd}^3 = \$408/\text{hr}$$

$$\$408.00/\text{hr} - (\$255.70/\text{hr} + \$14.93/\text{hr}) = \$137.37/\text{hr}$$

The cost of material per square meter, assuming an average wall thickness of eight inches, is $34.77.

Dividing other input costs by the hourly coverage rate gives $64.72 per square meter for labor and $3.79 per square meter for equipment. The total cost per square meter is $103.27.

Table A.16.9.1 summarizes the foregoing information. Normalizing the total rate to that of the more costly procedure, replacement, requires 3.95 ÷ 1.52 = 2.60 removal crews for each replacement crew.

TABLE A.16.9.1. Summary of Data for Removal and Replacement of Interior Concrete Walls

Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Removal	1.52	77.32	65.51	11.81	--
Replacement	3.95	103.27	64.72	3.79	34.77
Total	3.95	180.59	130.23	15.60	34.77

A.17 OTHER ASPHALT

Other asphalt refers to paved areas of smaller size than roads or large parking lots. Other asphalt surfaces are more likely to have restricted access than asphalt roads. Examples of other asphalt surfaces include driveways, sidewalks, and patios. Many of the operations described for asphalt roads are also applicable to other asphalt areas. However, because these other asphalt surfaces are smaller and have restricted access, production rates are likely to be slower. This could result from such things as the inability to use large-scale equipment. Therefore, where better data were lacking, costs for operations on other asphalt were estimated by doubling the costs per square meter and halving the production rate for the corresponding operation on asphalt roads. In some cases, independent cost and rate estimates for operations on other asphalt were developed in the corresponding sections on asphalt roads.

A.18 OTHER CONCRETE

The relationship between other concrete surfaces and concrete roads is the same as that between other asphalt and asphalt roads, as described in Section A.17. Moreover, cost estimates for other concrete surfaces are handled in the same manner as described in Section A.17.

A.19 VEHICLE TRANSPORT

Vehicles left in a contaminated area will need to be removed to a place where they can be decontaminated. Three ways to accomplish this are considered here. The first involves towing the vehicle out using a standard automobile tow truck. The cost of this procedure is estimated at \$50 per hour, with \$20 for labor, \$25 for equipment, and \$5 for fuel. The rate, in terms of vehicles removed per hour, is estimated at one. Therefore, costs per vehicle are the same as costs per hour. However, if the towing distance is particularly long, then the rate and costs per vehicle will have to be adjusted. Towing vehicles rather than driving them has the advantage of avoiding possible contamination of the interior of the engine, though it is not clear to what extent this poses a serious hazard.

The second means of vehicle transport involves using a vehicle transport truck such as is used to deliver new cars. The cost per vehicle is estimated at $40. Labor, comprising 40% of cost of the operation, costs $16 per vehicle. Equipment is estimated at $20 per vehicle, and fuel $4.00. The rate, in terms of vehicles per hour, is four.

The third means of vehicle transport is to drive the car out. This would involve transporting a driver to the vehicle using a van or bus. The driver would then drive the vehicle out. This method requires sufficient organizational coordination such that the driver will have the proper keys to operate the vehicle. Most of the cost of this operation is for labor. This accounts for $13.50 per vehicle, out of a total of $15.00. Fuel and equipment are for the bus or van and amount to $0.75 each per vehicle. The rate is two vehicles per hour.

A.20 AUTOMOBILE EXTERIORS

A.20.1 Ordinary Spray Wash

A standard spray wash of automobiles is a fairly effective technique for decontaminating the vehicle's exterior. Information for this operation was obtained from car wash businesses in the Richland, Washington area. These data are summarized in Table A.20.1.1. Also shown are the representative data.

TABLE A.20.1.1. Summary of Data for Ordinary Spray Wash of Automobiles

Source	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Columbia Industries	--	3.00	2.40	0.30	0.30
Walker's Hand Car Wash	--	--	(80%)	(10%)	(10%)
L.A. Hand Car Wash	--	6.00	--	--	--
Representative	4	5.00	4.00	1.00	1.00

A.20.2 Detailed Wash

This operation involves very thorough cleaning of the automobile's exterior. Also included is application of a protective coating. The information collected from businesses in the Richland, Washington area which perform this service is presented in Table A.20.2.1. Also shown are representative data.

A.20.3 Repainting

For severely contaminated automobiles, it may be necessary to repaint the exterior. This operation includes sanding the surface before painting. The collected and representative cost and rate data are presented in Table A.20.3.1.

TABLE A.20.2.1. Summary of Data for Detailed Washing of Automobile Exteriors

Source	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Tidy Car	--	100	--	--	--
Terry's Automotive Appearance	--	50	39	5	6
Representative	0.25	75	58.50	7.50	9.00

TABLE A.20.3.1. Summary of Data for Repainting Automobile Exteriors

Source	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Burkett's Auto Painting and Body Repair	--	300	--	--	--
Cascade Autobody and Paint, Inc.	--	950	600	114	236
Don's Auto Paint and Body	--	1500	900	75	525
Representative	0.083	900	558	72	270

A.21 AUTOMOBILE INTERIORS

A.21.1 Vacuum

Table A.21.1.1 presents data supplied by various businesses that perform vehicle vacuuming services. In addition, representative cost and rate data are also presented.

A.21.2 Detailed Vacuum and Clear

The data for detailed vacuuming and clearing of automobile interiors is shown in Table A.21.2.1. The crew includes two workers.

TABLE A.21.1.1. Summary of Data for Vacuuming of Automobile Interiors

Source	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Columbia Industries	--	2.00	1.70	0.20	0.10
Tidy Car	--	10.00	--	--	--
Walker's Hand Car Wash	--	--	85%	10%	5%
Representative	3	6.00	4.10	0.60	0.30

TABLE A.21.2.1. Summary of Data for Detailed Vacuuming and Cleaning of Automobile Interiors

Source	Rate (auto/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Tidy Car	--	55.00	--	--	--
Terry's Automotive Appearance	--	40.00	28.00	4.00	8.00
VIP Car Wash	--	35.00	--	--	--
Representative	1	45.00	31.50	4.50	9.00

A.21.3 Remove Contents, Clean, and Replace

This extensive operation provides a more thorough cleaning than detailed cleaning. The costs and rate for this operation are based on data supplied by Terry's Automotive Appearance. This source charges about $300 for the service. Of this amount, $240 is for labor and $30 for equipment and the same amount for materials.

A.21.4 Re-Upholstery

Re-upholstery is the most effective and most costly operation for automobile interiors. Table A.21.4.1 summarizes the information on this operation and shows the representative costs and rates.

TABLE A.21.4.1. Summary of Data for Re-Upholstering Automobile Interiors

Source	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Crawford's Custom Upholstering	--	600	--	--	--
Dean's Upholstery and Glass	--	600	210	180	210
Representative	0.14	600	210	180	210

A.22 AUTOMOBILE TIRES

The operations for decontaminating tires are water wash, wash and scrub, sandblast, and remove and replace. The cost for washing is based on the hourly cost for a common laborer ($17.45) plus equipment ($1.00). The wash and scrub cost figures are based on the hourly wash and scrub cost figures used for walls and floors (see Section A.9.2). The sandblast cost is based on the hourly cost of roof sandblasting (see Section A.3.6). The data for removal and replacement are based on information supplied by Les Schwab Tire Center and Ivan's American Tire Service.

TABLE A.22.1. Summary of Data for Different Tire Decontamination Operations

Operation	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Wash	10	1.85	1.75	0.10	--
Wash and Scrub	3	5.83	3.83	2.00	--
Sandblast	8	12.71	5.54	7.17	--
Remove and Replace	1	225	22.50	24.75	177.75

A.23 AUTOMOBILE ENGINES AND DRIVE TRAINS

Two techniques for decontaminating automobile engines and drive trains are steam cleaning and cleaning with an organic solvent. The data for these operations are presented in Table A.23.1.

A.24 HAULING

Hauling is not specific to any particular surface; rather it is an activity which is associated with other operations that generate contaminated material to be removed from the decontamination site to some dump site. Alternatively, some operations, notably those involving covering land areas

TABLE A.23.1. Summary of Data for Decontaminating Automobile Engines and Drive Trains

Operation and Source	Rate (autos/hr)	Cost (1982 $/auto) Total	Labor	Equipment	Materials
Steam cleaning					
Terry's Automotive Appearance	--	24.00	17.28	2.40	4.32
L.A. Hand Car Wash	--	28.00	--	--	--
Representative	1	26.00	18.72	2.60	4.68
Clean with solvent					
U.S. Ecology	--	37.00	35.15	0.35	1.40
Representative	1	37.00	35.15	0.35	1.40

with uncontaminated soil, involve hauling to the decontamination site. Also, it is possible that hauling materials away from the area being decontaminated could be coordinated with hauling materials to the site.

There are two principal variables affecting the cost per square meter of hauling. One is the distance of the haul. The other is the volume of material per square meter to be hauled. This latter variable depends on the particular operation and surface. These two important cost variables are discussed below.

The primary source of information for estimating the relationship between cost and distance is Means' Building Construction Cost Data 1982. There are different options for hauling crews. For example, debris boxes could be used rather than dump trucks. Dump trucks, however, seem to offer the greatest flexibility and would be significantly more costly than debris boxes only when truck loading is very slow.

The inputs for hauling are one heavy-truck driver at $19.75 per hour and one 20-cubic-yard dump truck at $45.84 per hour. The total hourly cost is $65.59. According to this source, loading a dump truck with a front-end loader takes 0.3 hours. For off-road work and short hauls, Means assumes an average vehicle speed of ten miles per hour. For longer distances, we assume higher average speeds.

Table A.24.1 shows the calculation of the costs of hauling per cubic meter. Most of the table is self explanatory. The third column, showing the time required for the haul, includes the time for loading and dumping. The cost per load is calculated by multiplying the hourly cost by the time. The cost per cubic meter is calculated by dividing the cost per load by 15.292 cubic meters per load. The rate is calculated by dividing 15.292 cubic meters per load by the time. Note that labor comprises 30% of the costs.

Given the cost per cubic meter for hauling, it is next necessary to estimate the volume of material per square meter for each operation requiring hauling in order to get a hauling cost per square meter. Table A.24.2 shows the estimated volume of material per square meter for each operation requiring hauling.

TABLE A.24.1. Estimated Hauling Costs and Rates by Mileage

Round Trip Distance (miles)	Avg. Vehicle Speed (mph)	Time (hrs)	Cost (1982 $) Per Load	Per m^3	Rate (m^3/hr)
1	10	0.4	26.24	1.72	38.23
2	10	0.5	32.80	2.14	30.6
3	10	0.6	39.35	2.57	25.5
4	10	0.7	45.91	3.00	21.8
5	10	0.8	52.47	3.43	19.1
10	15	0.9	63.43	4.15	15.8
20	25	1.1	72.15	4.72	13.9
30	30	1.3	85.27	5.58	11.8
50	40	1.55	101.66	6.65	9.9
100	40	2.80	183.65	12.00	5.5

TABLE A.24.2. Estimated Volume of Material Per Square Meter to be Hauled

Surface	Operation	Volume (m^3/m^2)
Agricultural fields	Scrape	0.15
	Clear	0.10
	Cover	0.15
Orchards	Scrape	0.12
	Remove and replace	0.10
	Cover - trees removed	0.15
	Cover - trees not removed	0.12
Vacant land	Clear	0.10
	Scrape	0.15
	Cover	0.15
Wooded land	Clear	0.22
	Grub and scrape	0.18
	Handscrape	0.15
	Cover, cleared land	0.15
	Cover, not cleared	0.15
Exterior wood walls	Remove and replace	0.08
	Remove structure	1.00
Exterior brick walls	Remove and replace	0.30
	Remove structure	1.00
Linoleum floors	Remove and replace	0.05
Wood floors	Remove and replace	0.20
Carpeted floors	Remove and replace	0.17
Painted interior wood, plaster walls	Remove and replace	0.20
Interior concrete walls	Scarify	0.025
	Remove and replace	0.30
Asphalt roads	Plane	0.083
	Resurface	0.083
	Remove and replace	0.33
Roofs	Remove and replace	0.20
Lawns	Close mow	0.04
	Remove and replace	0.11

APPENDIX B

This appendix discusses the decontamination efficiency figures used in this report. It is important to understand how these numbers were derived in order to properly interpret them. In general, existing decontamination efficiency data of the type relevant for this report is both scarce and weak. This reflects a different concern in previous decontamination studies. In particular, works such as Decontamination of Nuclear Reactors edited by J.A. Ayres, Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities prepared by E.S. Murphy as well as others are directed principally at intensive, highly effective decontamination measures applied to a relatively restricted area. In contrast, the hypothesized accident with which the present report deals is of a much larger scale. The scope of such an event precludes the use of decontamination methods which, though extremely effective, are too costly and too slow to be practical. Moreover, it would be necessary to employ techniques which could be performed in large part by personnel lacking in special training and skills for radiological decontamination. Thus, the focus of this study was on operations which are relatively inexpensive, which can be applied to large surface areas, and which require little or no special equipment or skills.

The hazard of radiation occurs through two distinct pathways. Inhalation and ingestion is one pathway, and external exposure is another. Some methods, therefore, will be more effective with respect to one pathway than the other. For example, a fixative may virtually eliminate resuspension and thereby nullify the danger of inhalation of radiation. However, the effect on reducing risk through exposure will be essentially nil. For this reason, each method has two efficiencies, one for each exposure pathway.

The radionuclide composition of the contamination will affect the initial relative hazards from the two pathways. Contamination due to a weapons accident would involve higher amounts of plutonium than would a nuclear reactor accident. The risk from plutonium is almost entirely through inhalation or ingestion.

In general, decontamination methods will be more effective against inhalation than exposure. Methods that involve fixing the contamination are effective in reducing exposure only to the extent that they also provide shielding. Methods that remove particles will reduce exposure risk for both pathways. However, the particles that remain after the decontamination treatment will tend to be more tenacious and thus less likely to become resuspended. Therefore, methods that remove radioactive particles, while effective for both pathways, will be more effective against inhalation and ingestion. Most of the sources reviewed for this report estimated decontamination efficiencies in terms of the inhalation pathway.

Also, the efficiency tests performed by most sources apparently did not experience rain between the original deposition and the decontamination activity. For methods in which the particles are removed, rain will generally lower the efficiency. On the other hand, since rain will tend to drive contamination into the surface, it will have the effect of reducing resuspension and lowering the inhalation hazard.

While several published sources were reviewed, there was sufficient novelty in our perspective that only a limited number provided substantial assistance. Among these, the often-cited report, "Operation Plumbob; Monitoring amd Decontamination Techniques for Plutonium Fallout on Large-Area Surfaces" by Dick and Baker, the Nuclear Weapon Accident Response Procedures Manual (NARP), prepared by the Department of Defense, a paper "Feasibility and Alternate Procedures for Decontamination and Post-Treatment Management of Pu-Contaminated Areas in Nevada" by A. Wallace and E.M. Romney, and "Decontamination After Widespread Release to the Environment" by J.R. Horan and L.J. Cunningham (printed in Ayres, Decontamination of Nuclear Reactors) were particularly helpful. They provided decontamination effectiveness data for operations such as vacuuming, sandblasting, high pressure hosing, and others when used on different surfaces. This information is given in Table B.1.

Additional data came from a Product Information Network report on street sweepers. This report listed removal rates for particles of various sizes and surface loadings. For example, for particle sizes less than 45 microns with an average surface loading of 11 pounds per curb mile, the average removal with a vacuumized street sweeper was 55 percent. The minimum removal was 18 percent and the maximum 77 percent.

Also, some useful information was found in the Nuclear Regulatory Commission document Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Appendix VI, Calculation of Reactor Accident Consequences, Appendix K. Table VI K-2 presented decontamination efficiencies of seven operations on several surfaces. That table is reproduced here. There were also a number of graphs showing a negative relationship between particle size and decontamination efficiency. These graphs are also reproduced. Care should be taken against reading too much in these graphs. For example, in Figure VI K-3, two lines are drawn on the basis of two data points for each. The information represented by a pair of data points was extrapolated to apply to particles of less than 60 microns in size, but the data are not really strong enough to warrant great confidence in the validity of this relationship.

Review of these data and the data used in other works such as "Radiological Dose Assessment and the Application and Effectiveness of Protective Actions for Major Property Types Contaminated by a Low-Level Radionuclide Deposition" (Julin et al. 1978) reveals that there are only a very few studies on the effectiveness of decontamination operations. These studies, done in the 1960s are cited repeatedly, and while they are based on actual field studies, the quantitative results have not been confirmed in later studies. The frequently listed studies are by Dick and Baker (Dick and Baker 1961), and one by Langham (unreferenced 1968). The fact that studies of 14 to

TABLE B.1. Summary and Comparison of Decontamination Data, Percent Decontamination of Various Surfaces by Method

Surface & Operation	NARP	Source: Wallace & Romney	Source: Horan & Cunningham
Highway asphalt			
Vacuum	52	37-72	75-98
Sandblast	95	92-99	
Steam cleaning	33	22-44	
Water	93		96-98
High pressure water scrub	95	94-96	
High pressure water w/detergent	98	98-99	
Detergent & scrub	98	96-99	
High pressure water		92-99	93-98
Wood float concrete			
Vacuum	56	56	
Sandblasting	98	98-100	
Steam cleaning	67	65-85	
Water	96		
High pressure water scrub	94	92	
High pressure water w/detergent	98	98-100	
Detergent & scrub	98	97-98	
High pressure water		97-98	
Unpaved land areas			
Plowing	98	97.9	
Oiling & scraping	98	95.6	
0.3" water leach & scraping	93	92.7	
0.3" water-$FeCl_3$ leaching	84	91.6	
Disking	76	89.2	
1.0" water leaching	85	87.4	
Scraping	95	86.0	98
Oiling	89	69.4	
0.3" water leaching		55.0	
0.3" water-Alconox		18.7	

TABLE B.1 (cont.)

Surface & Operation	Source: NARP	Wallace & Romney	Horan & Cunningham
ROOFS			
Asbestos shingles			
Vacuum	61	61	
Sandblast	100	100	
Steam cleaning	63	63	
Water	99		
High pressure water w/scrub	98	98	
High pressure water w/detergent	96	96	
Detergent & scrub	99	99	
High pressure water		99	90-97 ("composition" shingle)
Tar paper			
Vacuum	55	55	
Sandblast	99	99	
Steam cleaning	52	52	
Water	98		
High pressure water w/scrub	95	95	
High pressure water w/detergent	95	95	
Detergent & scrub	96	96	
High pressure		98	87.5-99 (tar & gravel)

TABLE VI K-2 HARD SURFACE DECONTAMINATION EFFICIENCIES IN PERCENT[a,b]

Material	Vacuum (D + 2)	High-Pressure Water (D + 3)	High-Pressure Water with Scrub (D + 12)	High-Pressure Water and Detergent (D + 4)	High-Pressure Water and Detergent with Scrub (D + 5)	Sandblasting (D + 9)	Steam Cleaning (D + 14)
Glass	98.95	98.85	97.79	100.00	99.76	100.00	97.86
Stucco	48.00	97.94	95.22	100.00	99.59	100.00	27.00
Painted wood	99.28	98.43	96.77	99.69	99.97	100.00	91.61
Unpainted wood	36.00	85.00	93.18	99.54	95.54	99.90	85.00
Aluminum	89.00	99.45	97.33	99.62	100.00	98.49	84.00
Plate Steel	93.04	97.26	94.19	100.00	93.83	99.72	91.46
Asbestos shingles	61.00	99.97	98.91	96.89	99.36	100.00	63.00
Unpainted wood shingles	61.00	97.16	90.49	95.01	57.93	99.82	71.00
Brick	29.00	99.46	99.32	99.14	99.56	99.92	97.50
Tarpaper	55.00	98.66	95.04	95.32	95.83	99.51	52.00
Galvanized roofing	89.00	99.36	97.19	99.73	99.86	100.00	85.00
Highway asphalt	32.00	99.90	96.25	90.82	99.48	99.90	44.00
Highway asphalt (10 x 10 ft)	72.00	92.45	94.95	98.85	96.34	92.73	22.00
Sealed Asphalt	71.00	98.67	90.00	100.00	99.72	99.61	84.00
Sealed asphalt (10 x 10 ft)	64.00	90.00	82.00	96.31	97.54	90.42	48.00
Steel trowel concrete	74.00	98.94	--	96.91	99.53	100.00	--
Steel trowel concrete (10 x 10 ft)	--	73.00	97.34	--	98.58	98.96	27.00
Wood float concrete	--	98.00	92.03	100.00	97.47	100.00	65.00
Wood float concrete (10 x 10 ft)	56.00	97.84	--	98.09	98.28	98.78	85.00
Average of all surfaces	65.40	96.12	94.59	98.61	98.64	98.83	67.80

[a] From Dick and Baker (1961)

[b] Decontamination factor (DF) = 100/[100 - decontamination efficiency (%)];
(D + n) = number of days between contamination and decontamination.

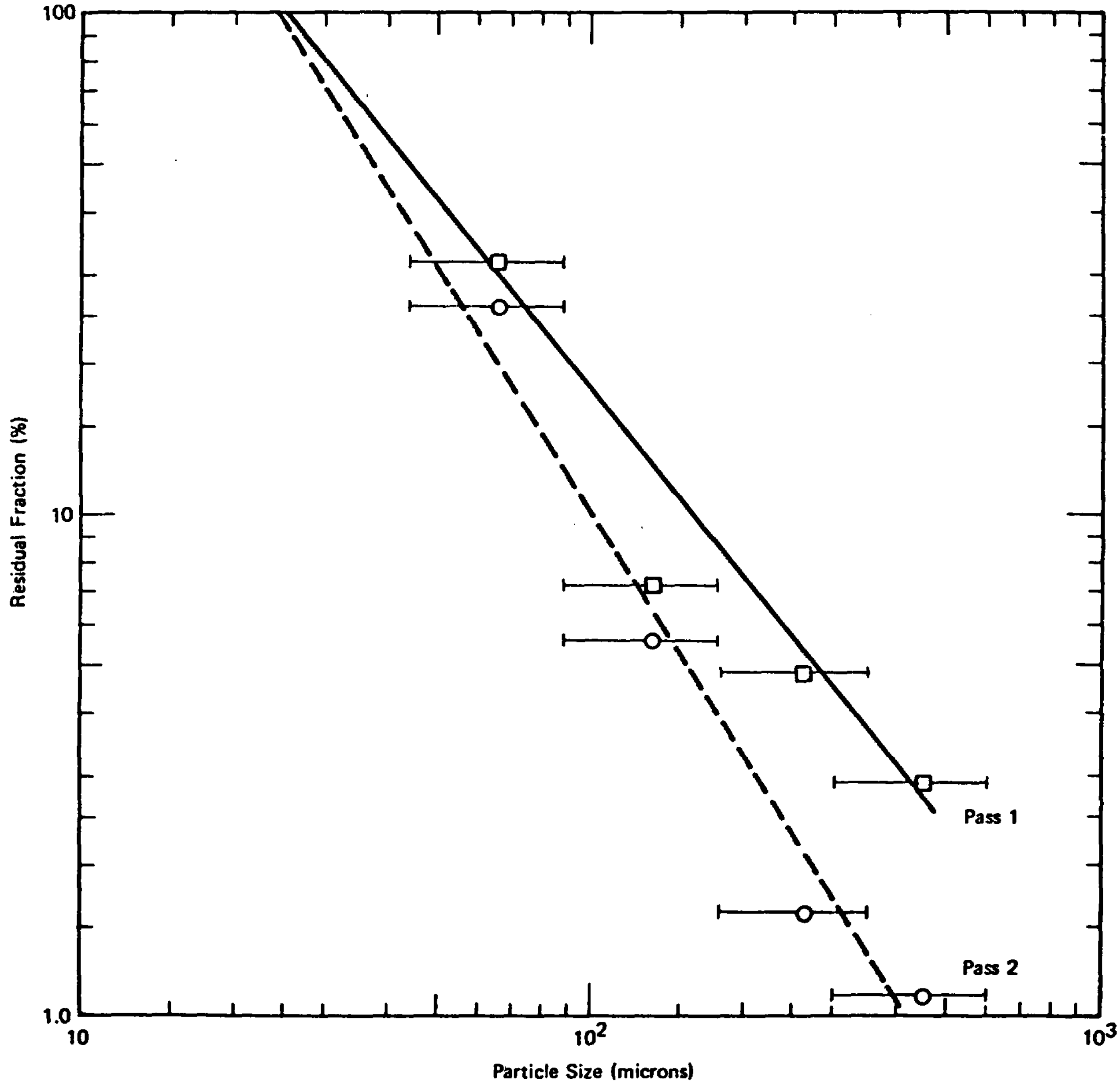

FIGURE VI K-1 Decontamination of roughly textured asphalt (or concrete) by firehosing (standard nozzle). Initial mass loading = 25 g/ft^2. [DF = 100/residual fraction (%).]

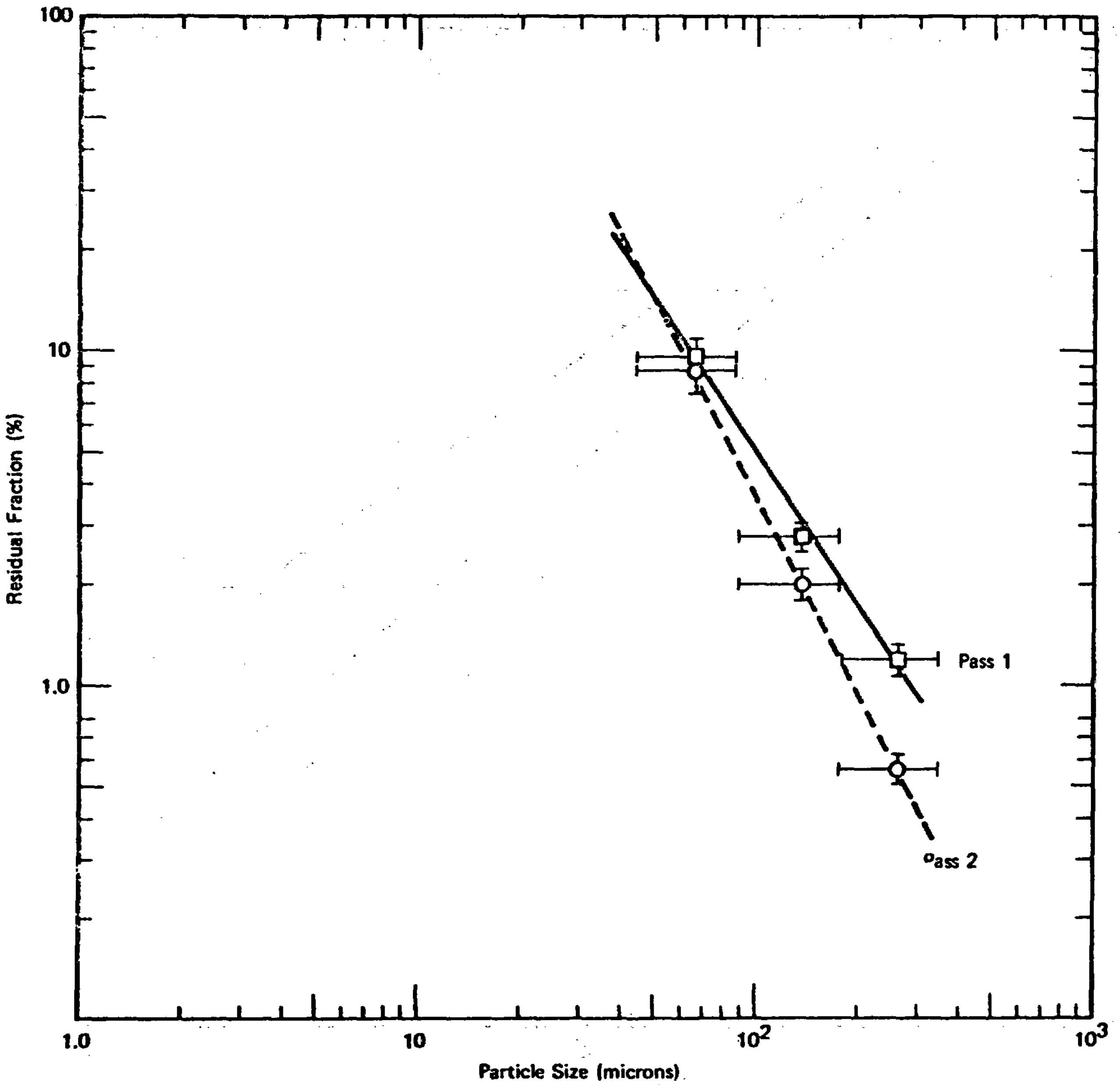

FIGURE VI K-2 Decontamination of smoothly textured asphalt (or concrete) by firehosing (standard nozzle). Initial mass loading = 25 g/ft^2. [DF = 100/residual fraction (%).]

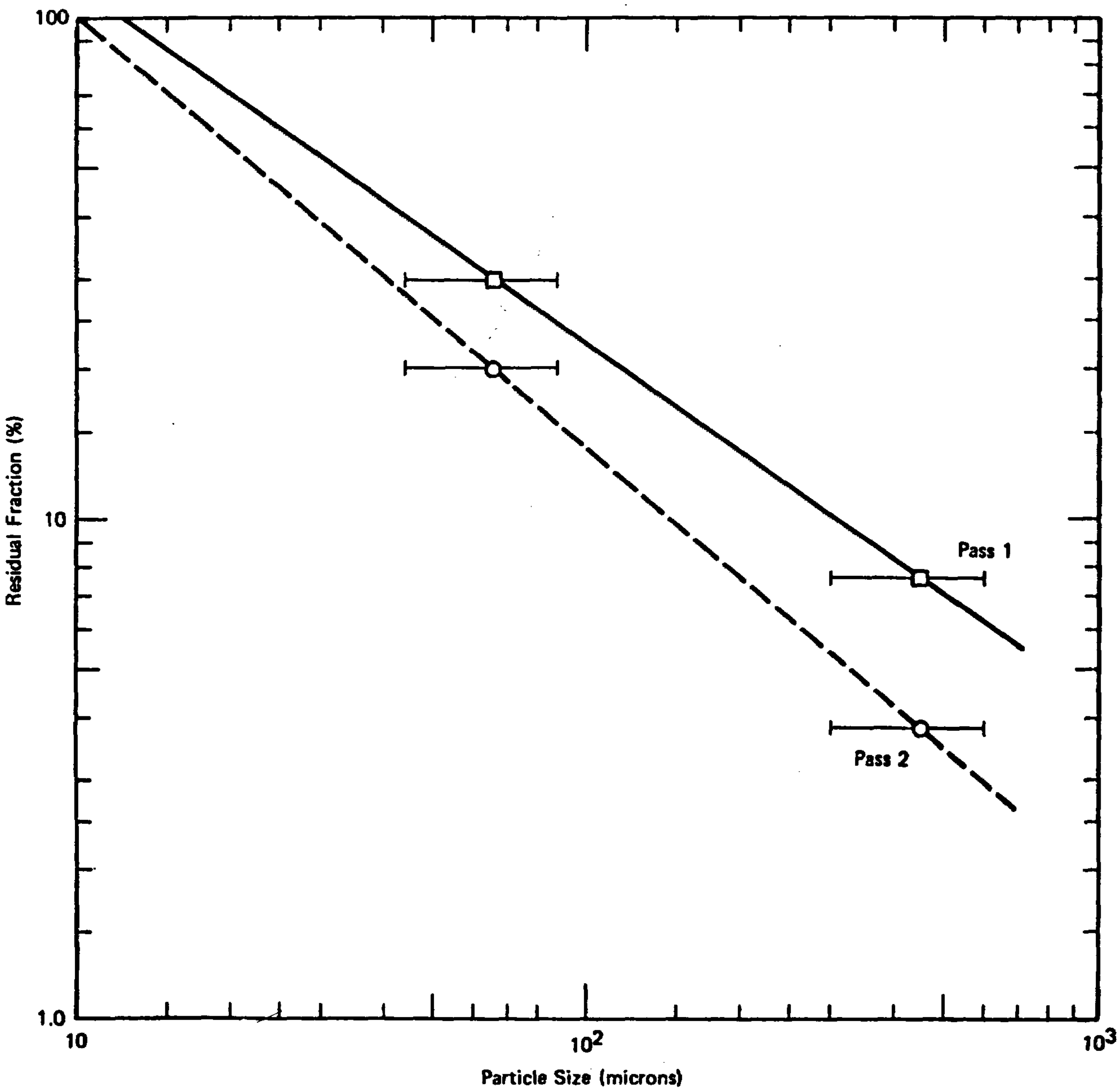

FIGURE VI K-3 Decontamination of roughly textured asphalt (or concrete) by firehosing (standard nozzle). Initial mass loading = 5 g/ft^2. [DF = 100/residual fraction (%).]

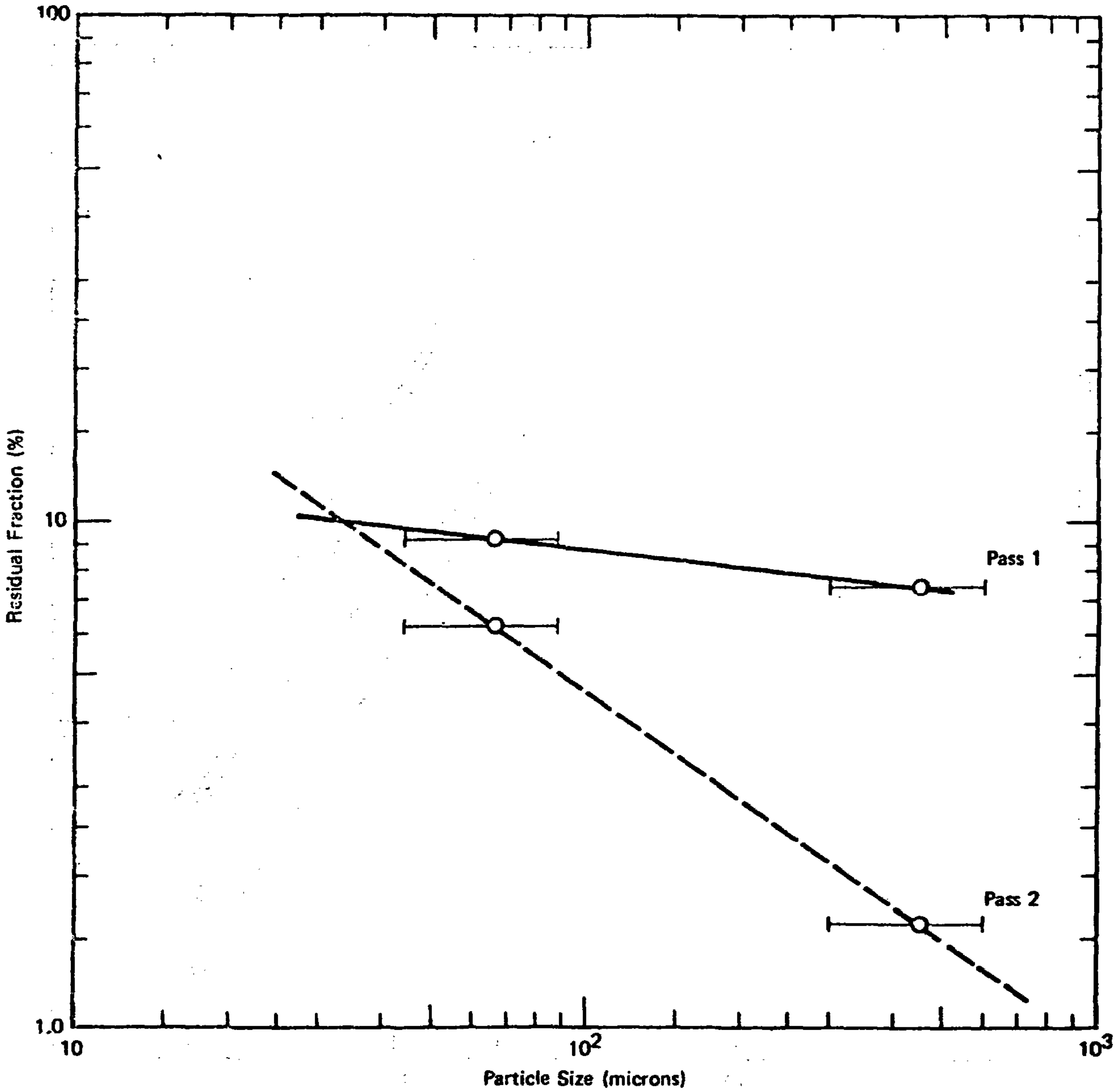

FIGURE VI K-4 Decontamination of smoothly textured asphalt (or concrete) by firehosing (standard nozzle). Initial mass loading = 5 g/ft^2. [DF = 100/residual fraction (%).]

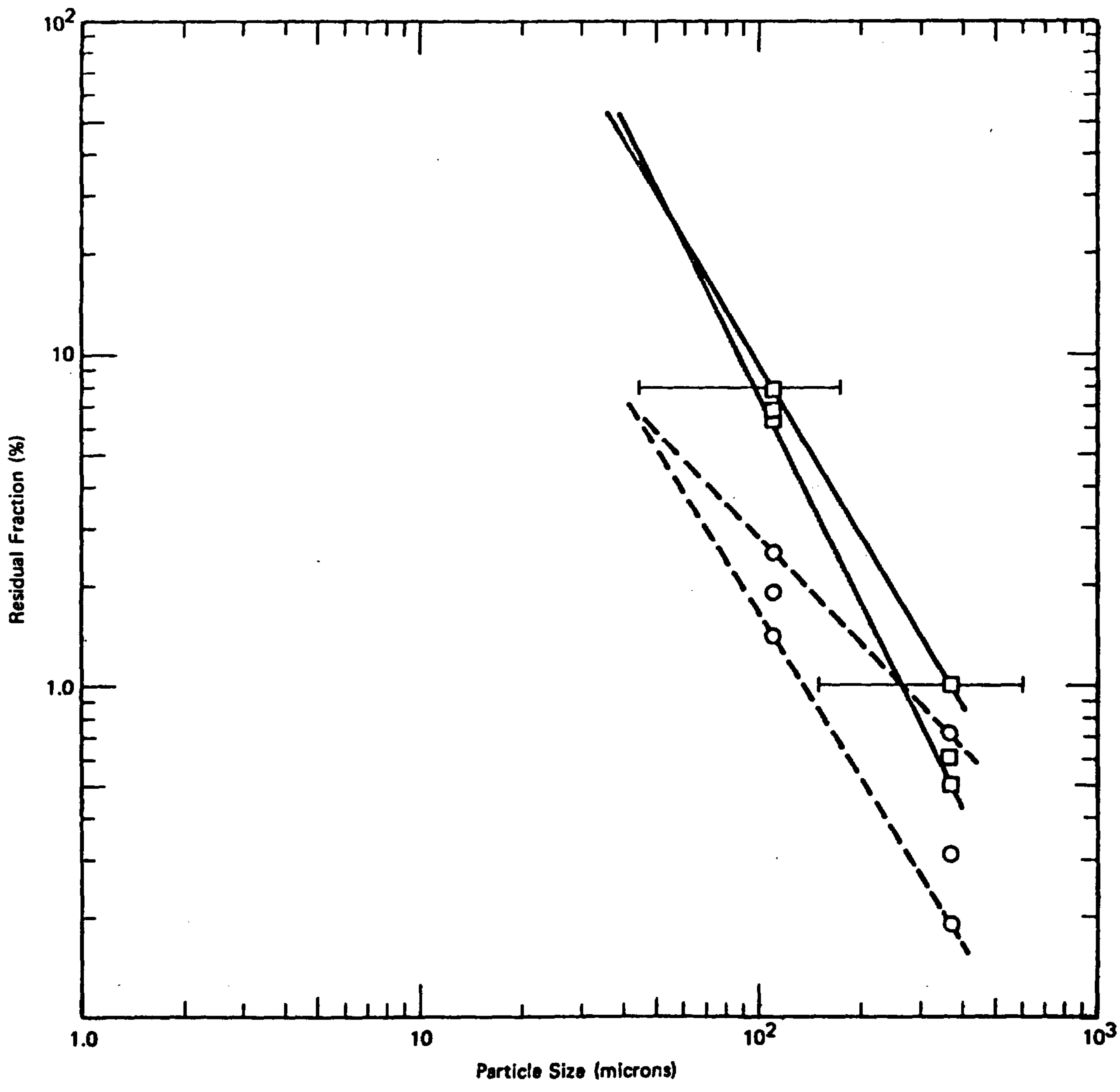

FIGURE VI K-5 Decontamination of roughly textured asphalt (or concrete) by mechanized flushing (three consecutive passes). Initial mass loading = 5 g/ft^2 (□) and 25 g/ft^2 (○). [DF = 100/ residual fraction (%).]

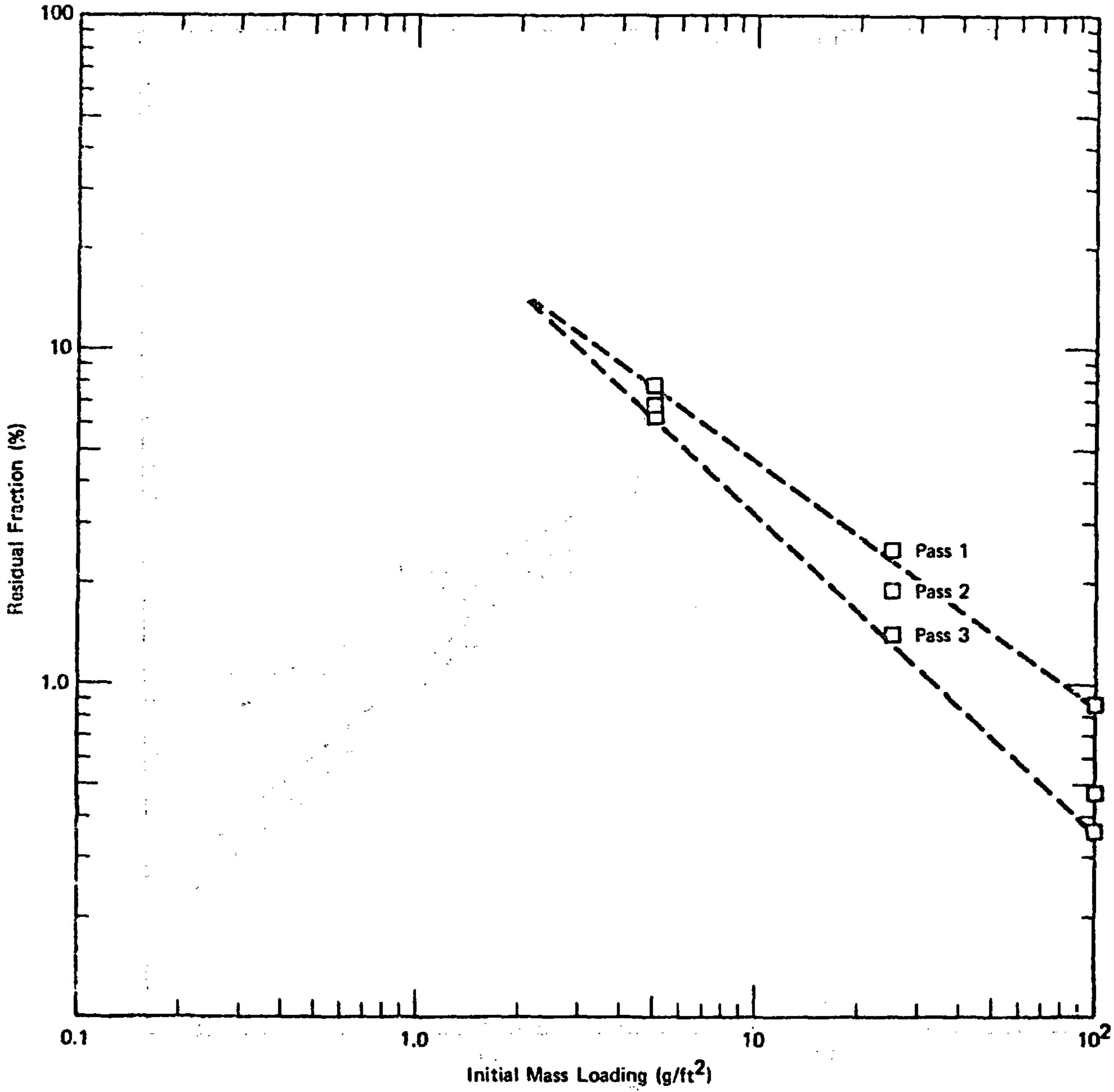

FIGURE VI K-6 Decontamination of roughly textured asphalt (or concrete) by mechanized flushing. Particle size = 44 to 100 microns. [DF = 100/residual fraction (%).]

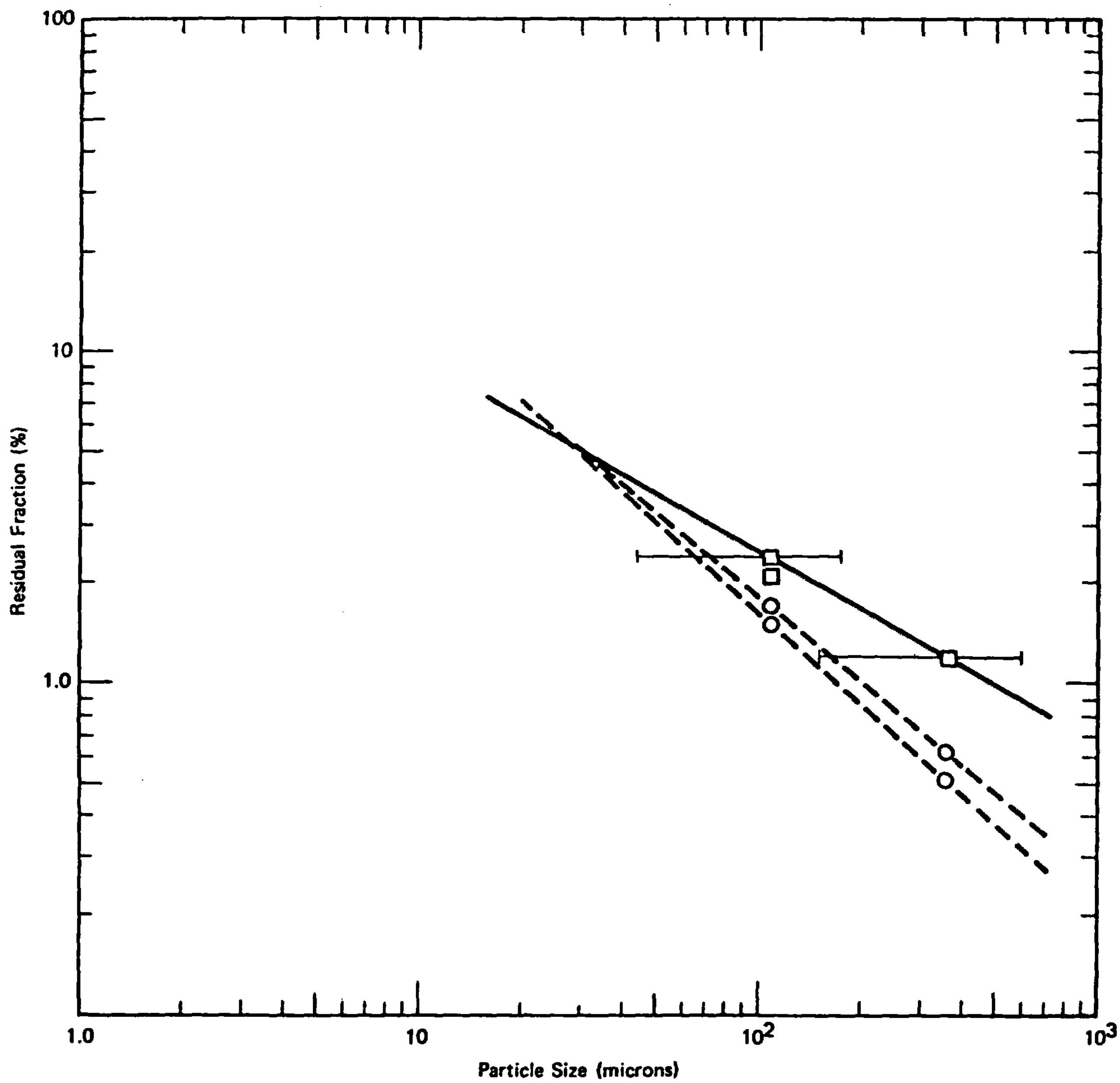

FIGURE VI K-7 Decontamination of smoothly textured asphalt (or concrete) by mechanized flushing (two consecutive passes). Initial mass loading = 5 g/ft^2 (□) and 12 g/ft^2 (○). [DF = 100/residual fraction (%).]

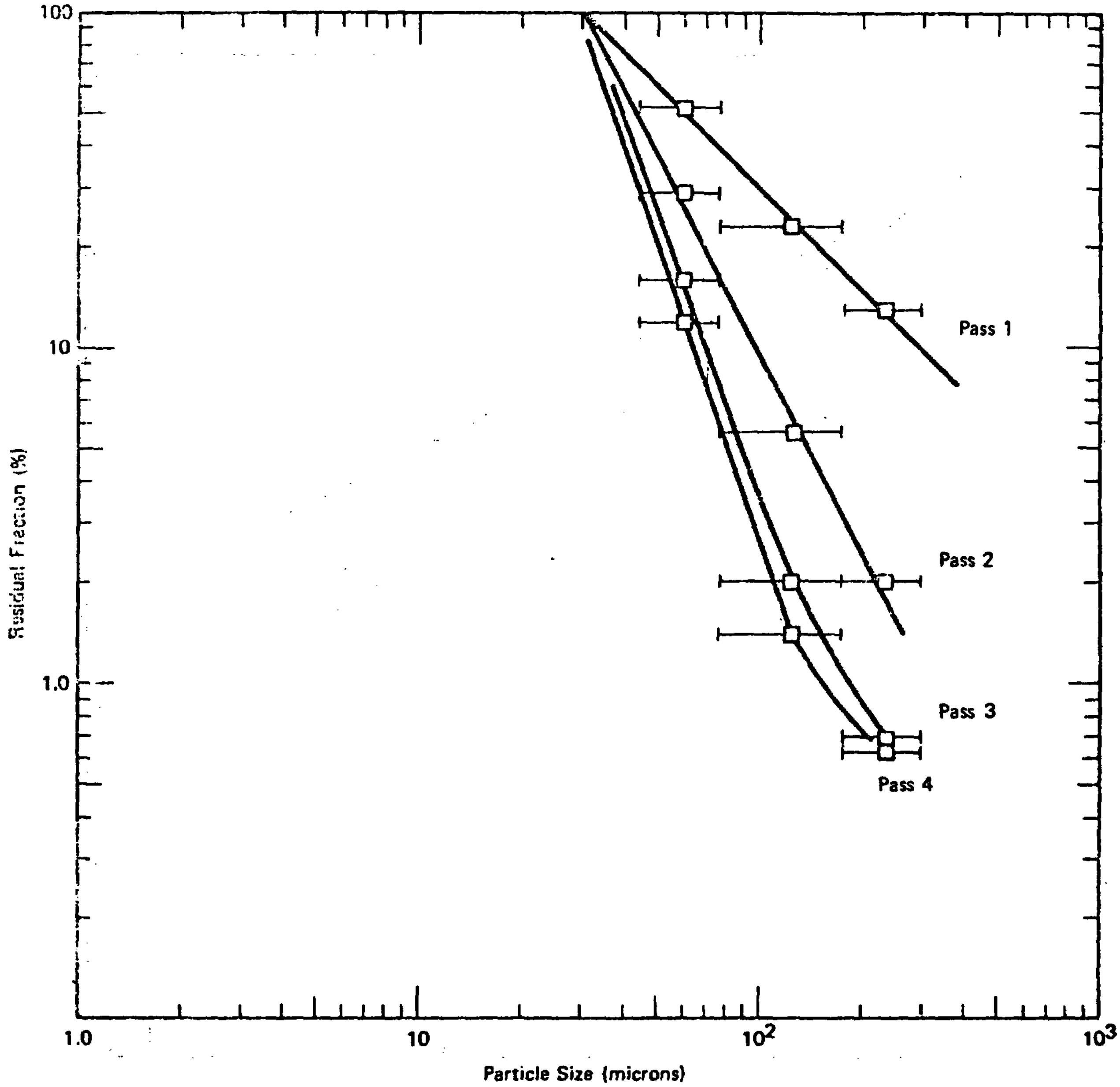

FIGURE VI K-8 Decontamination of roughly textured asphalt (or concrete) by "vacuumized" sweeper. Initial mass loading = 25 g/ft^2. [DF = 100/residual fraction (%).]

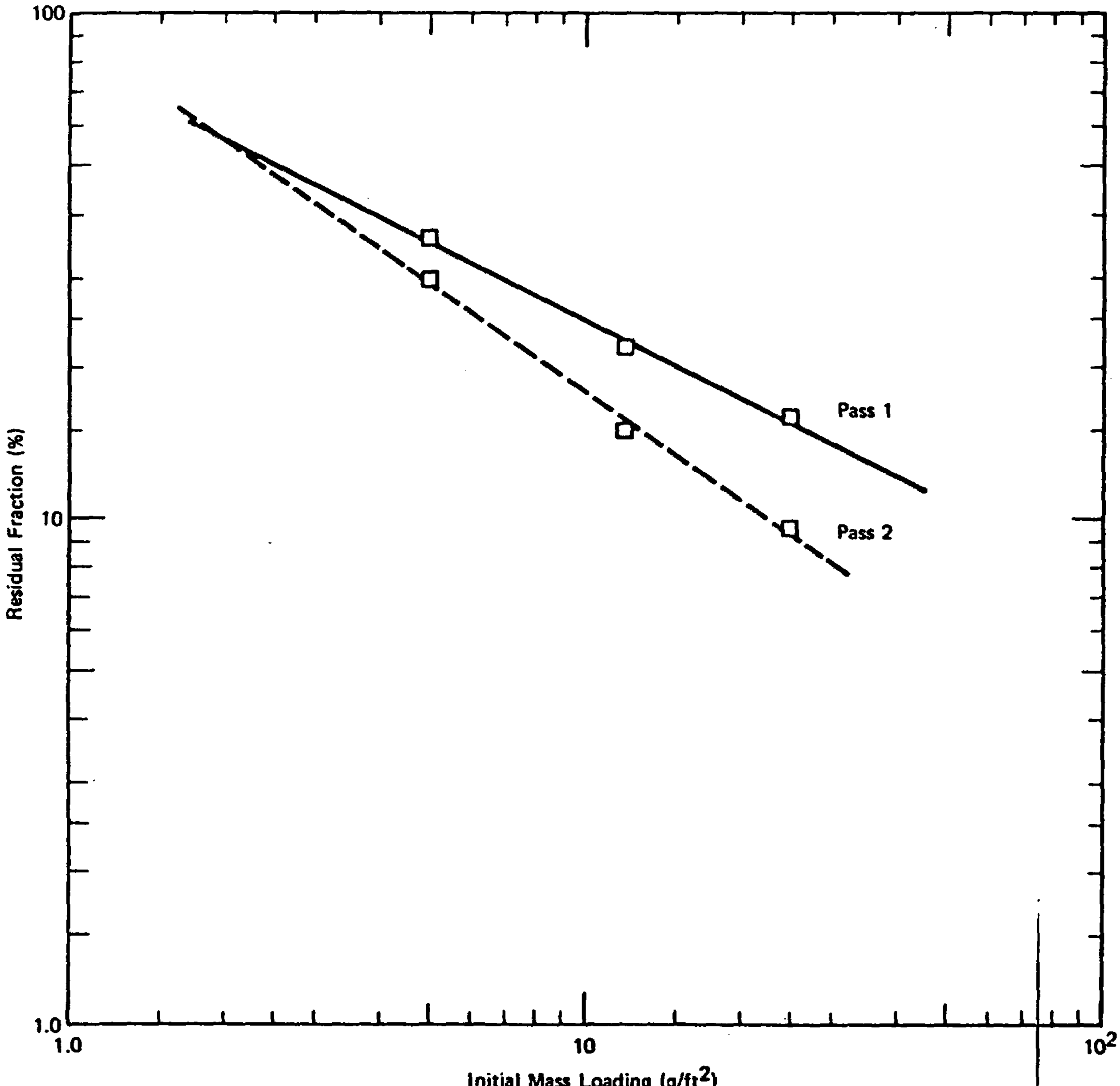

FIGURE VI K-9 Decontamination of roughly textured asphalt (or concrete) by "vacuumized" sweeper. Particle size = 44 to 74 microns. [DF = 100/residual fraction (%).]

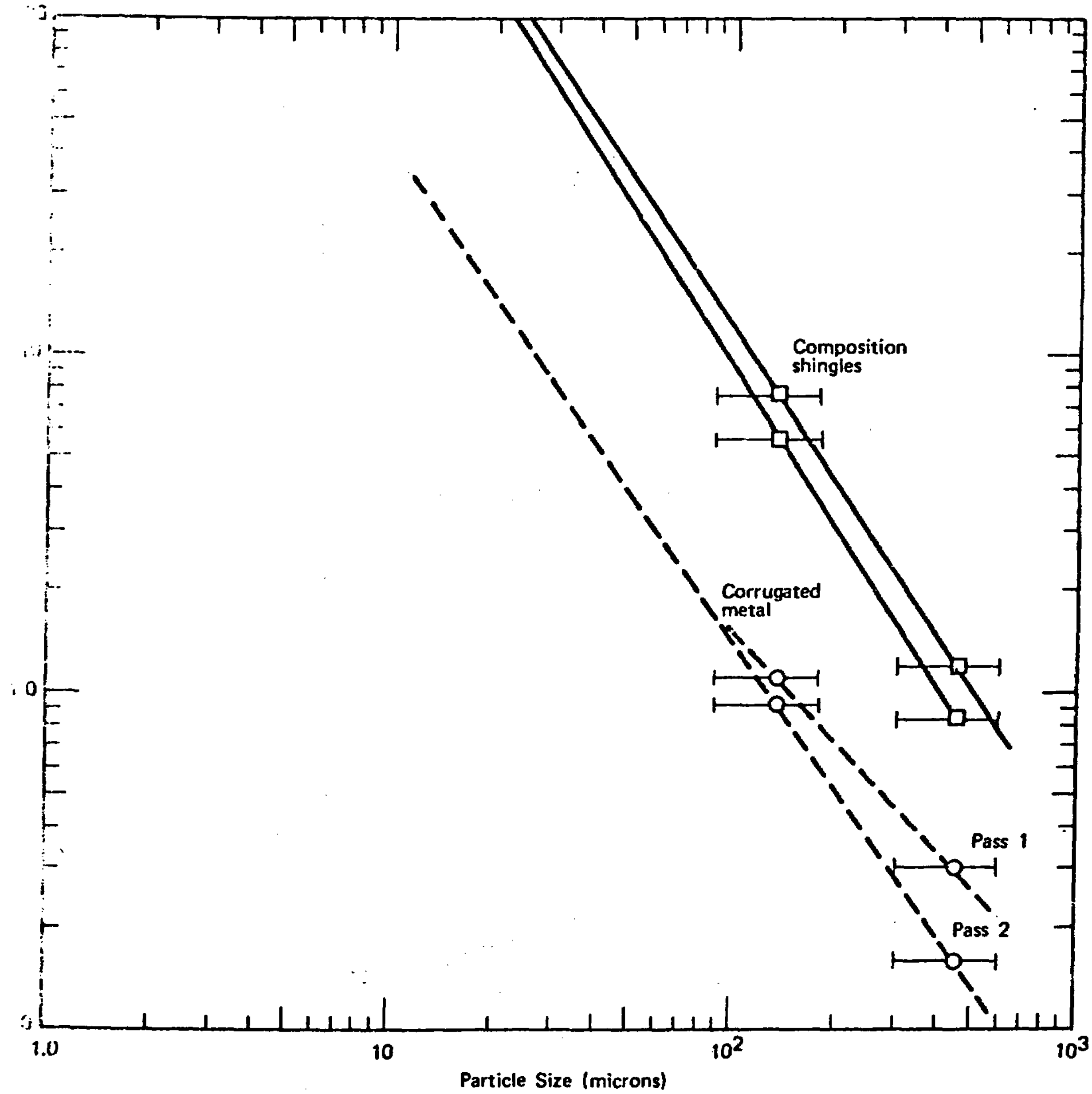

FIGURE VI K-10 Decontamination of sloped roofs by firehosing. Ini... loading = 25 g/ft^2. [DF = 100/residual fraction

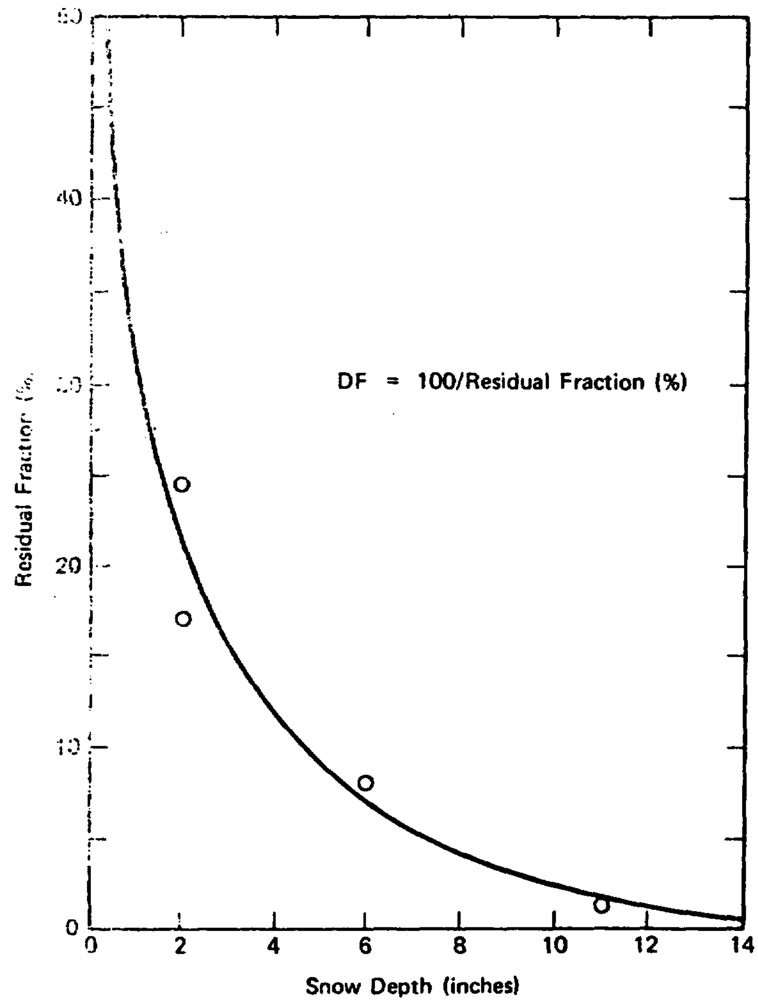

FIGURE VI K-11 Influence of snow depth on the decontamination effectiveness of the rotary snow blower. From Owen et al. (1967).

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20 years past are the prime data sources is indicative of the scarcity of information in this area.

In addition to the shortage of alternate data sources, the sources that were available did not provide sufficient detailed information about the operations. For example, the amount of water used in high and low pressure hosing was not given. The implication of these data limitations, however, is not as great as it might seem. Since decontamination efficiencies for several methods were reported for each surface, certain judgements about the relative effectiveness of the methods can be made. Thus, it is fairly clear from the data given in Table B.1 that steam cleaning is a less effective method of decontaminating highway asphalt than high pressure water with scrubbing. Using relative efficiency levels, efficiencies for the various operations were estimated. It should be clear from this discussion that these estimates should be interpreted more as indices of relative effectiveness rather than as highly accurate measures of the absolute effectiveness.

The efficiency issue becomes more clouded when various operations are combined, and in this area information was even more sparse, as most sources provided information only on a single decontamination treatment done once. Clearly, the effect of performing one operation before another will be to reduce the effectiveness of the second. The actual reduction will depend on the specific nature of the two operations. Thus, vacuuming pavement before a low pressure water wash will not greatly diminish the success of the second step. However, were the order of the operations to be reversed, the net outcome would be less effective. This is because any particles not removed by the water would tend to be driven into surface crevices by the water, making vacuum removal less productive.

Provided in this Appendix is Table B.2, a listing that shows the various methods for each surface and each method's net inhalation and exposure efficiencies. In interpreting this table, the number in the first column to the left of the decimal point designates the surface. The surfaces and their numbers are shown in Table B.3. The number after the decimal point is simply a consecutive number of each method for that surface.

The next column shows the mnemonic code defining the operation. The key to these mnemonic codes is given in Table B.4, which is reproduced from Table 1.1.

The next two columns show the estimated net inhalation and exposure efficiencies for that method.

Table B.2. Removal Efficiencies for Decontamination Methods

AGRICULTURAL FIELDS

	Meth	Efficiency Inhal	Efficiency Exter
01.1	W	55.	25.
01.2	WW	79.8	43.75
01.3	WWW	90.9	57.8
01.4	WWWW	95.9	68.4
01.5	T	65.	0.
01.6	E	92.	35.
01.7	N	30.	30.
01.8	X	86.	86.
01.9	A	90.	50.
01.10	Y	98.	60.
01.11	TN	40.	40.
01.12	TNX	96.	96.
01.13	TNx	99.44	99.44
01.14	TNxX	99.92	99.92
01.15	G	60.	40.
01.16	WG	84.7	55.
01.17	TG	89.5	42.
01.18	LG	97.6	70.
01.19	XG	94.4	91.6
01.20	AG	97.	91.
01.21	YG	99.4	97.
01.22	NG	72.	58.
01.23	GG	88.	64.
01.24	GGG	96.4	78.4
01.25	WWG	93.9	66.3
01.26	TX	96.	96.
01.27	Tx	99.44	99.44
01.28	TxX	99.92	99.92
01.29	TA	92.	55.
01.30	TY	98.5	65.

ORCHARDS

	Meth	Efficiency Inhal	Efficiency Exter
02.1	W	33.	15.
02.2	WW	47.9	26.3
02.3	WWW	54.5	34.7
02.4	WWWW	57.5	41.
02.5	X	48.	48.
02.6	A	51.	27.
02.7	TDX	80.	68.
02.8	TDx	90.32	78.
02.9	TX	75.	51.
02.10	TDXW	77.3	71.
02.11	TRX	93.6	93.6
02.12	TO	72.5	18.
02.13	TOA	93.3	45.
02.14	TRXG	95.	94.56
02.15	g	30.	24.
02.16	Tg	33.	25.2
02.17	Wg	47.9	33.
02.18	TRXa	95.7	95.1
02.19	T	50.	0.
02.20	TOA	93.3	45.

Table B.2. (continued)

VACANT LAND

	Meth	Efficiency Inhal	Efficiency Exter
03.1	N	30.	30.
03.2	TN	40.	40.
03.3	TNX	96.	96.
03.4	W	55.	25.
03.5	WW	79.8	43.8
03.6	WWW	90.9	57.8
03.7	WWWW	95.96	68.4
03.8	TA	92.	55.
03.9	TY	98.5	65.
03.10	TNx	99.44	99.44
03.11	TNxX	99.92	99.92
03.12	G	60.	40.
03.13	TG	86.	42.
03.14	WG	82.	55.
03.15	NG	72.	58.
03.16	TNG	76.	64.
03.17	WWG	91.9	66.3
03.18	WWWG	96.4	74.7
03.19	TAG	96.8	73.
03.20	TYG	99.4	79.
03.21	TNxG	99.776	99.664
03.22	GG	84.	64.
03.23	T	65.	0.
03.24	A	98.	95.
03.25	TNxx	99.989	99.989

WOODED LAND

	Meth	Efficiency Inhal	Efficiency Exter
04.1	TD	48.	00.
04.2	TN	65.	40.
04.3	TNX	85.	85.
04.4	TNx	89.25	89.25
04.5	TH	67.5	42.5
04.6	TDH	77.5	69.5
04.7	TNG	70.	60.
04.8	THG	72.	45.5
04.9	T	50.	0.
04.10	TX	67.5	42.5
04.11	TNH	85.	85.

EXTERIOR WOOD WALLS

	Meth	Efficiency Inhal	Efficiency Exter
05.1	W	90.	85.
05.2	J	95.	90.
05.3	WJ	94.	90.25
05.4	V	99.	94.
05.5	VW	99.3	94.
05.6	VJ	99.6	95.5
05.7	H	98.	93.
05.8	VH	99.7	97.9
05.9	TR	99.9	99.9
05.10	VTR	99.985	99.985
05.11	vTR	99.998	99.998
05.12	VF	99.8	98.5
05.13	C	85.	84.
05.14	vF	99.825	98.65
05.15	vFR	99.94	99.6
05.16	TZ	99.999	99.999
05.17	VC	99.6	97.3
05.18	T	65.	0.
05.19	VT	99.5	94.

EXTERIOR BRICK WALLS

	Meth	Efficiency Inhal	Efficiency Exter
06.1	V	29.	25.
06.2	v	36.1	30.25
06.3	W	90.	85.
06.4	VW	91.48	86.5
06.5	VF	92.9	88.75
06.6	vF	92.971	88.84
06.7	vW	91.693	86.748
06.8	VTR	99.716	99.7
06.9	vTR	99.744	99.721
06.10	vFR	99.8594	99.928
06.11	VH	91.48	87.25
06.12	vH	91.69	87.445
06.13	vFH	95.78	92.746
06.14	C	40.	35.
06.15	VU	96.45	92.5
06.16	vU	96.49	92.67
06.17	VJ	92.19	88.375
06.18	vJ	92.33	88.49
06.19	VO	99.29	99.25
06.20	vO	99.30	99.26
06.21	VTZ	99.716	99.7
06.22	T	65.	0.
06.23	F	92.	87.

Table B.2. (continued)

LINOLEUM FLOORS

	Meth	Efficiency Inhal	Efficiency Exter
07.1	V	99.	95.
07.2	v	99.3	96.25
07.3	J	97.	95.
07.4	VJ	99.85	99.
07.5	VF	99.9	99.25
07.6	vF	99.895	99.25
07.7	vJ	99.86	99.06
07.8	VTR	99.998	99.99
07.9	vTR	99.999	99.991
07.10	vFTR	99.9991	99.992
07.11	C	98.	97.
07.12	VC	99.6	97.85
07.13	T	80.	0.

CARPETED FLOORS

	Meth	Efficiency Inhal	Efficiency Exter
09.1	V	60.	55.
09.2	v	72.	66.25
09.3	VF	80.	75.25
09.4	vF	83.2	78.0625
09.5	vFF	86.56	81.353
09.6	VTR	99.52	99.46
09.7	vTR	99.636	99.56
09.8	VI	72.8	67.2
09.9	VJ	76.	70.8
09.10	vI	78.16	72.
09.11	vJ	79.9	73.

WOOD FLOORS

	Meth	Efficiency Inhal	Efficiency Exter
08.1	V	90.	85.
08.2	v	94.5	91.
08.3	J	92.	87.
08.4	VJ	95.	91.
08.5	VF	97.5	95.5
08.6	vF	98.08	96.4
08.7	vJ	95.9	92.8
08.8	VTR	99.97	99.955
08.9	vTR	99.98	99.973
08.10	vFTR	99.994	99.989
08.11	VTK	99.96	99.94
08.12	vTK	99.976	99.964
08.13	vFTK	99.9916	99.9856
08.14	C	80.	75.
08.15	VC	97.0	94.5
08.16	T	85.	0.0
08.17	H	95.	90.

CONCRETE FLOORS

	Meth	Efficiency Inhal	Efficiency Exter
10.1	V	74.	69.
10.2	v	83.1	78.61
10.3	J	85.	80.
10.4	VJ	94.8	92.56
10.5	VF	97.4	95.66
10.6	vF	97.63	96.15
10.7	vJ	95.775	94.0108
10.8	VTK	99.792	99.752
10.9	vTK	99.8648	99.8289
10.10	vFTK	99.9730	99.9606
10.11	C	95.	90.
10.12	VU	98.96	97.52
10.13	vU	98.99	97.647
10.14	VH	96.1	94.11
10.15	vH	96.789	95.2942
10.16	VC	96.62	94.42
10.17	vC	97.296	95.508

Table B.2. (continued)

INTERIOR WOOD/PLASTER WALLS

	Meth	Efficiency Inhal	Exter
11.1	V	99.	95.
11.2	v	99.3	96.25
11.3	J	97.	95.
11.4	VJ	99.85	99.
11.5	VF	99.9	99.25
11.6	vF	99.895	99.25
11.7	vJ	99.86	99.06
11.8	VTR	99.998	99.99
11.9	vTR	99.999	99.991
11.10	vFTR	99.9991	99.992
11.11	C	98.	97.
11.12	VC	99.6	97.85
11.13	T	80.	0.

INTERIOR CONCRETE WALLS

	Meth	Efficiency Inhal	Exter
12.1	V	70.	65.
12.2	v	79.	74.1
12.3	J	80.	75.
12.4	VJ	92.5	89.85
12.5	VF	95.5	93.35
12.6	vF	95.8	94.04
12.7	vJ	93.7	91.43
12.8	VTR	99.76	99.412
12.9	vTR	99.832	99.7928
12.10	vFTR	99.958	99.942
12.11	C	90.	85.
12.12	VH	94.	91.6
12.13	vH	94.96	93.007
12.14	VU	97.3	95.45
12.15	vU	97.69	95.61
12.16	VC	91.3	88.45
12.17	vC	93.28	90.676

ASPHALT STREETS/PARKING

	Meth	Efficiency Inhal	Exter
13.1	V	50.	45.
13.2	v	67.5	61.5
13.3	W	95.	85.
13.4	VW	95.5	86.25
13.5	VF	97.5	91.75
13.6	vF	98.05	91.915
13.7	vW	95.775	86.525
13.8	VR	99.5	99.45
13.9	vR	99.675	99.615
13.10	vFR	99.9805	99.9192
13.11	VK	99.25	98.9
13.12	vK	99.5125	99.23
13.13	vFK	99.9708	99.8383
13.14	C	97.5	93.
13.15	VP	99.	49.4
13.16	vP	99.35	64.58
13.17	VG	99.25	71.4
13.18	vG	99.5125	79.98
13.19	VC	98.	96.15
13.20	T	97.75	2.0
13.21	vC	98.375	93.455
13.22	F	97.	90.
13.23	vCF	99.8375	98.36

CONCRETE STREETS/PARKING

	Meth	Efficiency Inhal	Exter
14.1	V	50.	45.
14.2	v	67.5	61.5
14.3	W	95.	85.
14.4	VW	95.5	86.25
14.5	VF	97.5	91.75
14.6	vF	98.05	91.915
14.7	vW	95.775	86.525
14.8	VR	99.5	99.45
14.9	vR	99.675	99.615
14.10	vFR	99.9805	99.9192
14.11	VK	99.25	98.9
14.12	vK	99.5125	99.23
14.13	vFK	99.9708	99.8383
14.14	C	97.5	93.
14.15	VP	99.	53.8
14.16	vP	99.35	67.66
14.17	VG	99.25	71.4
14.18	vG	99.5125	79.98
14.19	VC	98.	96.15
14.20	T	97.75	2.0
14.21	vC	98.375	93.455
14.22	F	97.	90.
14.23	vCF	99.8375	98.36

Table B.2. (continued)

ROOFS

	Meth	Efficiency Inhal	Efficiency Exter
15.1	V	60.	50.
15.2	S	99.	96.
15.3	H	97.	93.
15.4	F	93.	90.
15.5	C	85.	80.
15.6	W	90.	85.
15.7	WW	98.	96.25
15.8	R	99.9	99.
15.9	VH	98.	95.
15.10	VW	92.	87.5
15.11	TR	99.94	99.8

AUTO INTERIORS

	Meth	Efficiency Inhal	Efficiency Exter
19.1	V	75.	70.
19.2	v	92.5	89.5
19.3	D	95.	90.
19.4	DD	96.	92.
19.5	R	99.	99.
19.6	Vz	98.	97.

LAWNS

	Meth	Efficiency Inhal	Efficiency Exter
16.1	V	30.	20.
16.2	W	85.	75.
16.3	WW	91.	84.
16.4	WWW	93.	86.88
16.5	WWWW	94.	88.06
16.6	M	65.	65.
16.7	R	98.	98.
16.8	L	85.	80.
16.9	TRW	99.9	99.7
16.10	TRL	99.92	99.9
16.11	TR	99.	99.

AUTO TIRES

	Meth	Efficiency Inhal	Efficiency Exter
20.1	R	99.9	99.9
20.2	W	60.	55.
20.3	J	90.	85.
20.4	S	95.	88.

AUTO EXTERIORS

	Meth	Efficiency Inhal	Efficiency Exter
18.1	W	85.	80.
18.2	WW	96.25	93.
18.3	J	95.	94.
18.4	JJ	99.5	99.28
18.5	K	99.9	99.8

AUTO ENGINE/DRIVE TRAIN

	Meth	Efficiency Inhal	Efficiency Exter
21.1	I	75.	65.
21.2	II	92.5	86.
21.3	E	95.	90.
21.4	IE	97.5	94.75
21.5	IEE	99.625	98.95

Table B.2. (continued)

	OTHER PAVED ASPHALT				OTHER PAVED CONCRETE		
		Efficiency				Efficiency	
	Meth	Inhal	Exter		Meth	Inhal	Exter
23.1	V	50.	45.	24.1	V	50.	45.
23.2	v	67.5	61.5	24.2	v	67.5	61.5
23.3	W	95.	85.	24.3	W	95.	85.
23.4	VW	95.5	86.25	24.4	VW	95.5	86.25
23.5	VF	97.5	91.75	24.5	VF	97.5	91.75
23.6	vF	98.05	91.915	24.6	vF	98.05	91.915
23.7	vW	95.775	86.525	24.7	vW	95.775	86.525
23.8	VR	99.5	99.45	24.8	VR	99.5	99.45
23.9	vR	99.675	99.615	24.9	vR	99.675	99.615
23.10	vFR	99.9805	99.9192	24.10	vFR	99.9805	99.9192
23.11	VK	99.25	98.9	24.11	VK	99.25	98.9
23.12	vK	99.5125	99.23	24.12	vK	99.5125	99.23
23.13	vFK	99.9708	99.8383	24.13	vFK	99.9708	99.8383
23.14	C	97.5	93.	24.14	C	97.5	93.
23.15	VP	99.	49.4	24.15	VP	99.	49.4
23.16	vP	99.35	64.58	24.16	vP	99.35	64.58
23.19	VC	98.	96.15	24.19	VC	98.	96.15
23.20	T	97.75	2.0	24.20	T	97.75	2.0
23.21	vC	98.375	93.455	24.21	vC	98.375	93.455
23.22	F	97.	90.	24.22	F	97.	90.
23.23	vCF	99.8375	98.36	24.23	vCF	99.8375	98.36

TABLE B.3. Surfaces and Their Corresponding Numbers

Number	Surface
01	Agricultural fields
02	Orchards
03	Vacant land
04	Wooded land
05	Exterior wood walls
06	Exterior brick walls
07	Linoleum floors
08	Wood floors
09	Carpeted floors
10	Concrete floors
11	Painted wood, plaster interior walls
12	Interior concrete walls
13	Asphalt roads
14	Concrete roads
15	Roofs
16	Lawns
18	Automobile exterior
19	Automobile interiors
20	Automobile tires
21	Automobile engine and drive train
23	Other asphalt surfaces
24	Other concrete surfaces

TABLE B.4. Decontamination Operations

A	Plow	P	Thin Asphalt/Concrete Layer
B	Vacuum Blast	Q	Very High Pressure Water
C	Strippable Coating	R	Remove and Replace
D	Defoliate	S	Sandblasting
E	Leaching, EDTA	T	Surface Sealer/Fixative
F	Foam	U	Hydroblasting
G	Three-Inch Asphalt and	V	Vacuum
G	Cover with 6" Soil (No Trees)	W	Low Pressure Water
H	High Pressure Water	X	Scrape 4"-6"
I	Steam Clean	Y	Deep Plow
J	Wash and Scrub; Shampoo Carpet	Z	Remove Structure
K	Resurface	g	Cover with 6" Soil (Trees in Place)
L	Leaching, $FeCl_3$	h	Hand Scrape
M	Close Mowing	t	Fixative, Aerial Application
N	Clear; Harvest	v	Double Vacuum
O	Plane, Scarify; Radical Prune	x	Double Scrape

Operations to Automobiles

D	Detailed Auto Cleaning	T	Tow
E	Clean Engine with Solvent	V	Vacuum
I	Steam Clean	W	Water
J	Wash and Scrub	c	Drive Auto Out
K	Repaint	m	Auto Transport Truck
R	Replace/Reupholster	v	Double Vacuum
S	Sandblasting	z	Remove Interior/Clean/Replace

APPENDIX C

The following list gives the names of people and organizations which generously supplied information or helped in the search for information used for the cost estimates of the decontamination operations.

A-Z Pest Control
Richland, Washington
(509) 783-3211
Jim Nichols

AAA Spraying
Seattle, Washington
(206) 364-4283

American Building Maintenance
Seattle, Washington
(206) 325-8800

American Institute of Architects
Washington, D.C.
(202) 626-7494
Stephanie Byrnes

American La France
Elmira, New York
(607) 734-8181
Guy Dewey

American Maintenance Systems
Seattle, Washington
(206) 226-2340
Lisa Hurlocker

American Public Works Association
Chicago, Illinois
(312) 667-2200
William Forester
Robert Flemming
Mary Sasso

American Road and Transportation
Builders Association
Washington, D.C.
(202) 488-2722

Associated Landscape Contractors of America
McLean, Virginia
(703) 821-8611

J.T. Baker Chemical Co.
Phillipsburg, New Jersey
(201) 859-2151

Jerald K. Bell, Landscape Architect
Seattle, Washington
(206) 362-9137

Blue Grass Chemical Specialities
New Albany, Indiana
(812) 948-1115

Butler Aviation
Redmond, Oregon
(503) 548-8166
Leo Demers

C&M Landscaping
Richland, Washington
(509) 946-0221
Jeff Markham

Cal-Trans
State of California
Sacramento, California
(916) 445-4300
Chet Fields
Kathy Peterson

Oliver B. Cannon & Son
Richland, Washington
(509) 377-2327
Oscar Rickman

Chemwest Industries
San Francisco, California
(415) 421-8745
Kevin White
Kathy Hutchings

Chicago Roofing Contractors Assoc.
Chicago, Illinois
(312) 887-9072

Columbia Aerial Ag Service, Inc.
Pasco, Washington
(509) 545-8826
Richard Skupa

Conservation Chemical Co.
Kansas City, Missouri
(913) 262-3649
Norman Hjersted

Dow Chemical
Midland, Minnesota
(517) 636-1000

DuPont, E.I. DeNemours & Co.
Chemicals, Dyes and Pigments Dept.
Wilmington, Delaware
(800) 441-9475
(800) 441-9442

Elite Sod Farm
Richland, Washington
(509) 627-3148
Dianne Enningham
Dale Kenyon

Emergency One, Inc.
Osala, Florida
(904) 237-1122
John Oakley

Evergreen Spray Service
Richland, Washington
(509) 943-4968

FMC Corporation
Pomona, California
(714) 629-4071
Rick Clayton

Golf Course Superintendents Assoc.
Laurence, Kansas
(913) 841-2240

C.P. Hall
Chicago, Illinois
(312) 767-4600

Home Builders Association
Washington, D.C.
(202) 822-0200

International Association of Fire Chiefs
Washington, D.C.
(202) 833-3420
Nowell Patten

City of Kennewick
Street Department
Kennewick, Washington
(509) 586-4181
Earl Gavaert
Rick Olson

Lawn and Garden Manufacturers Association
Chicago, Illinois
(312) 644-6610

City of Los Angeles
Department of Public Works
Los Angeles, California
(213) 485-5691
Bill Harding

National Contract Sweepers Assoc.
Scotts Valley, California
(408) 438-5423
Jim Mills

Nurserymen's Association
Washington, D.C.
(202) 737-4060

Oakite Products
Richland, Washington
(509) 582-9079
Mike Denby

City of Pasco
Department of Public Works
Pasco, Washington
(509) 545-3463
(509) 545-3441
Jim Ajax
Jim Edwards

City of Portland
Department of Public Works
Portland, Oregon
(503) 248-5545
Jack Griffen

Power Master
Portland, Oregon
(503) 257-8801
Ken Crevier
Jerome Rushon
George Dodson

Public Technology
Washington, D.C
(202) 626-2400
Jeremy O'Brien

City of Richland
Fire Department
(509) 943-9161
Robert Panuccio, Chief

City of Richland
Street Department
(509) 943-9161
Dallas Phillips

Rockwell International
Richland, Washington
(509) 373-2102
Lester Bruns

City of San Francisco
Department of Public Works
San Francisco, California
(415) 558-4058
John Busher

Roger's Spray & Tree Service
Seattle, Washington
(206) 244-1717

City of Seattle
Fire Department
(206) 625-4073
Robert Hanson, Chief
Dave Lawson
Jack Seim
Richard Columbi

City of Seattle
Department of Maintenance
Seattle, Washington
(206) 625-4732
Morey Hilliard

Sherman Supply & Salvage Co.
Seattle, Washington
(206) 622-4801
Murray Federman

Sod-Growers Association of Mid-America
Palos Hills, Illinois
(312) 974-3419

City of Spokane
Department of Public Works
Spokane, Washington
(509) 456-4300
Warren Anington

Spokane Community College
Administrative Services
Spokane, Washington
(509) 456-3988
Don Kolb

True Value Hardware Store
Richland, Washington
(509) 946-5532

Turco Products
Carson, California
(213) 775-2111
Don Steiner
Bub Zaelke

U.S. Bureau of Land Management
Interagency Fire Center
Boise, Idaho
(208) 334-9421
Bob Weber
Bill Lyon

U.S. Department of Agriculture
Forest Service
Portland, Oregon
(503) 294-5393
Dick Pierce

U.S. Department of Agriculture
Forest Service
Seattle, Washington
(206) 442-5400
Jim Brain

U.S. Department of Agriculture
Forest Service
Fire Management Section
Wenatchee, Washington
(509) 662-4335
Ed Susich

U.S. Department of Transportation
Federal Highway Administration
Interstate Reports Branch
Washington, D.C.
FTS 426-0404
Mr. Shuffleburger

U.S. Department of Transportration
Federal Highway Administration
Policy Planning Branch
Washington, D.C.
FTS 426-0226
Bill Reulein

City of Walla Walla
Public Works Department
Walla Walla, Washington
(509) 527-4463
Max Graybeal

Wajax Firefighting Equipment
Seattle, Washington
(206) 243-4343
Ray Carr

State of Washington
Office of Emergency Services
Olympia, Washington
(206) 459-9191
Terry Simmons

State of Washington
Olympia, Washington
(206) 753-3605
Tom Brace, Fire Marshal

State of Washington
Department of Transportation
Maintenance Section
Olympia, Washington
Bob Lee

State of Washington
Department of Transportation
Olympia, Washington
(206) 753-2129
Dennis Jackson

Washington Tree Service
Seattle, Washington
(206) 362-9100

City of Yakima
Fire Department
Yakima, Washington
(509) 575-6060
Ed Carrol, Chief

APPENDIX D

This appendix describes the use of the DECON support programs. These programs include

- REFDATA - prepares reference database
- RADGRID - prepares site database for radial grid
- IRRGRID - prepares site database for irregular grid
- UNIGRID - prepares site database for uniform grid
- GETDOSE - determines dose at any map location given centerline dose
- RUNGRID - organizes radial grid pattern; determines isopleths for different exposure levels

The programs are described in the sections that follow.

D.1 REFDATA

REFDATA is a program for preparing the reference database. It consists of a main program and four subroutines. The input files for REFDATA are:

- COSTS.DAT - contains the costs and rates of each decontamination operation
- FACTOR.DAT - contains the factor inputs for each decontamination operation
- EFFNCS.DAT - contains the removal efficiencies of each decontamination method
- PARM.DAT - contains the program control parameters

REFDATA creates the following output files:

- CODEX.DAT - contains the codes for each decontamination method
- MTHDAT.DAT - a random access file containing the data for each decontamination method.

D.2 RADGRID

RADGRID is a program for preparing the site database for a radial grid. It consists of a main program and three subroutines, RADGRID, IMPUTE and XFORMA. The input files for REFDATA are:

- PARM.DAT - contains the program control parameters
- DOSEGE.DAT - contains the dose (commitment) at the midpoint of each grid element
- OFFSITE.DAT - contains site-specific data by political subdivision
- XFORM.DAT - contains the coefficients for subroutine XFORM

RADGRID creates the following output file:

- SITEDB.DAT - a random access file containing the site-specific data for each grid element.

D.3 IRRGRID

IRRGRID is a program for preparing the site database for a grid with irregular-shaped grid elements. It consists of a main program and two subroutines, IRRDATA and XFORM. The input files for IRRGRID are:

- PARM.DAT - contains the program control parameters
- DOSEXXX.DAT - contains the dose (commitment) at the midpoint of each grid element
- SITEXXX.DAT - contains site-specific data available by township
- XXXDATA.DAT - contains assorted site-specific data by county
- XFORM.DAT - contains the coefficients for subroutine XFORM

IRRGRID creates the following output file:

- SITEDB.DAT - a random access file containing the site-specific data for each grid element.

D.4 UNIGRID

UNIGRID is a program for preparing the site database for a grid with grid elements all of the same size. It is a special case of the more general program IRRGRID and has the same input and output files.

D.5 GETDOSE

GETDOSE is a program for computing the exposure level at any point on a map downwind from the point of radiological release. The point can be off the plume centerline. GETDOSE uses as inputs the doses or dose commitments at specified downwind distances and the plume width parameters. To find the dose at any point on the map, the user first enters the map scale--number of miles per inch. He then enters the distance (measured orthogonally) from the point of interest to the centerline, followed by the centerline distance from the point of release. The distances are entered in map-inches to simplify the process.

GETDOSE uses interpolative methods to compute the exposure levels. There will often be one or more points off of the centerline but close to the release point that must be computed. To compute these, the user will have to supply one or more exposure levels and distance intervals closer to the release point that the first distance interval of interest. For example, if the first distance interval of interest is 0.5 miles from the point of release, then the user may have to supply the exposure level along the centerline at 0.25 miles from the point of release. The number of these "extra" points will depend upon the accuracy required.

The user must respond to the following questions from the console:

- ENTER DATA NUMBER OF FIRST DISTANCE - This is equal to the number of "extra" data points plus one.
- ENTER NUMBER OF DISTANCE INTERVALS - This is equal to the number of data points, excluding the "extras".

ENTER NUMBER OF GRID SECTORS - This is equal to the number of radial sectors that divide the accident site; 16 sectors (each of $22\text{-}1/2^{o}$) is common.

ENTER NAME OF INPUT FILE - Self-explanatory.

ENTER NAME OF OUTPUT FILE - Self-explanatory.

MAP SCALE--ENTER THE NUMBER OF MILES PER INCH - Enter the map scale.

ENTER ORTHOGONAL DISTANCE FROM LOOK-UP POINT - Draw a line from the look-up point to the centerline and at right angles to the centerline. Enter the length of this line in inches.

ENTER CENTERLINE DISTANCE FROM ORIGIN - Measure the length, in inches, of the centerline from the release point to where it intersects the orthogonal line. Enter this distance.

GETDOSE will respond with "DOSE = ________". GETDOSE will then ask for the orthogonal distance from the next look-up point. To end the interactive session, enter a negative value for the orthogonal distance.

D.6 RUNGRID

RUNGRID is a program for organizing a radial grid. It will 1) produce a table showing the plume width, the incremental and the total areas covered by the plume for each downwind distance interval; 2) print out a map of the accident site, with a number for each grid element; and 3) print out a dose map of the accident site.

The user must respond to the following questions from the console:

ENTER DATA NUMBER OF FIRST DISTANCE - This is equal to the number of "extra" data points plus one. (See Section D.5.)

ENTER NUMBER OF DISTANCE INTERVALS - This is equal to the number of data points, excluding the "extras".

ENTER NUMBER OF GRID SECTORS - This is equal to the number of radial sectors that divide the accident site; 16 sectors (each of $22\text{-}1/2^{o}$) is common.

ENTER NAME OF DOSE FILE - Name of file containing the dose data.

ENTER A VALUE FOR THE LOWEST RADIATION LIMIT TO BE CONSIDERED - This value is used to find the outer boundaries of the area covered by the plume.

RUNGRID will then print out a table showing the plume width, incremental area covered by the plume, and total area covered by the plume for each downwind distance. Then, a grid map of the accident area will be printed. Finally, a map showing the dose (commitment) at the midpoint of each grid element will be printed. The user is then given an opportunity to 1) process a new dose file (enter '0'); repeat the process, but with a different radiation limit (enter '1'); exit from program (enter '-1').

D.7 FILES USED IN PRECEDING PROGRAMS

Codes for Decontamination Methods; CODEX.DAT - Unit 5

This file is prepared by the program REFDATA, which prepares the reference database (see Appendix D). CODEX.DAT must be on the default drive.

Labels for Surface Types; SRFLBL.DAT - Unit 6

This file is modified only when changing the number or types of surfaces supported by the reference database. SRFLBL.DAT must be on the default drive.

Labels for Factor Inputs; NPTLBL.DAT - Unit 7

This file is modified only when changing the number or types of factor inputs supported by the reference database. NPTLBL.DAT must be on the default drive.

Data from the Reference Database; MTHDAT.DAT - Unit 8

This file is prepared by the program REFDATA. It is modified only when adding data to or changing data in the reference database. See Appendix D. MTHDAT.DAT must be on the default drive.

Parameter Values; PARM.DAT - Unit 10

This file is prepared by the user and must reside on the default drive. The variables read and the format in which the variables must appear is described below.

The following 11 variables are read in Fortran format (9I8).

NGE - number of grid elements in the site database

NSURF - number of surface types in the reference database; current value is 24 (numbers 17 and 22 are not currently used).

NMAX - maximum number of decontamination methods available for any surface. The current value is 30.

LNDUSE - the number of land use categories. The current value is 11, and the categories are as follows: 1) residential, 2) commercial, 3) industrial, 4) streets and roads, 5) wooded areas, 6) parking lots, 7) grain crops, 8) vegetable crops, 9) orchards, 10) vacant land and 11) automobiles.

NPUTS - the number of factor inputs. The current value is 99.

NORGUS - the number of body organs to be processed. The maximum value for NORGUS is currently 1.

IJM - the number of decontamination methods in the reference database. The current value is 348.

IJS - the number of decontamination operations in the reference database. The current value is 186.

NTP - the number of time periods to be considered. Any value from 1 to 30, inclusive.

I20 - the number of exposure intervals to be used. Any value from 1 to 20, inclusive.

IACT - Set to 0 if batch processing mode is used; set to 1 if interactive mode at console is used. (Current implementation is only for IACT=1.)

The variable (NUMSRF(I),I=1,NSURF) is read in format (9I8). NUMSRF contains the number of decontamination methods available for each surface. The current values for NUMSRF are: 30, 20, 25, 13, 19, 23, 13, 16, 11, 17, 13, 17, 23, 23, 11, 11, 0, 5, 6, 4, 5, 0, 21, 21.

The variable (RADLIM(I),I=1,NORGUS) is read in format (9F8.2,F7.2). RADLIM contains the radiation limit, exposure limit, or cleanup criterion with respect to NORGUS body organs. RADLIM must be in the same units of measurement as GCE, which is read from the site database. The units of GCE are user-selectable. (The current implementation of DECON requires that NORGUS equal 1.)

The variable (XGCE(I),I=1,I20) is read in format (9F8.2,F7.2). XGCE contains the upper bound of each exposure (dose, dose commitment, or ground concentration) interval. The value of GCE is read for each grid element in the site database, and it is then determined in which of the XGCE exposure intervals GCE falls. The grid element is then processed as though GCE were equal to the value of XGCE for the interval in which it falls. For example, if XGCE(3)=7.8, XGCE(4)=9.2 and GCE=8.1, then GCE will fall in exposure interval 4 and the grid element will be processed as though GCE had equaled 9.2. In specifying the XGCE, the value for XGCE(1) should normally be set equal to zero, the value for XGCE(2) should be set equal to the minimum value for RADLIM, and the last nonzero value for XGCE should be equal to or slightly greater than the largest value of GCE in the site database.

The variable (DEPR(I),I=1,LNDUSE) is read in format (9F8.2,F7.2). DEPR contains the depreciation rates to be associated with each land use category. The values for the DEPR are expressed as the fraction of the property value lost from one year to the following year. For example, DEPR(3)=0.1 means that property in land use category 3 (industrial) loses 10 percent of its value every year due to depreciation.

The variable (DISC(I),I=1,LNDUSE) is read in format (9F8.2,F7.2). DISC contains the fraction of a property's pre-accident value that is lost because of residual contamination remaining after it has been decontaminated. For example, DISC(9)=0.2 means that property in land use category 9 (orchards) would lose 20 percent of its pre-accident value simply as a result of residual contamination.

The next set of variables read from PARM.DAT is P1, P2, P3, P4 and SCALE. The format is (9F8.2,F7.2). P1 through P4 are factors that can be used to adjust the costs of labor (P1), equipment (P2), materials (P3) and fuel (P4). These costs are actually adjusted in the program REFDATA, which also uses the file PARM.DAT.

For severe accidents, the costs, areas and hours of labor and equipment are large numbers and need to be scaled down if they are to be expressed in fixed decimal format. The variable SCALE permits the user to scale the output results. SCALE is usually expressed as some power of 10, and is entered in PARM.DAT in scientific notation. For example, the value 1.0E+03 would cause values expressed in dollars, areas, and hours of labor and equipment to be scaled down by a factor of 1000.

The last variable, (EXPOS(I),I=1,NSURF), is read in format (9F8.2,F7.2). EXPOS contains the exposure factors to be associated with each type of surface. Exposure factors are discussed in Section 4.3.5, page 4.19 and illustrated in Section 5.3.6, page 5.26. It is recommended that the values for EXPOS be set to 1.0 for base case evaluations.

Data Relating to Doses; DOSE.DAT - Unit 12

This file contains the decay factors (see DECAY in common block DOSE). It is prepared by the dose model. See Appendix D. DOSE.DAT must be on the default drive.

Data Relating to the Site Database; SITEDB.DAT - Unit 13

This file, which is prepared by the program SITEDATA, contains all of the information relating to the site database. One random access record is provided for each grid element. Each record contains 1) the pre-accident value of the property within the grid element; 2) the post-decontamination value of the property (as computed from the variable, DISC); 3) the exposure level (dose, dose commitment or ground concentration); 4) the population; 5) for each surface type, the ratio of the area for that surface type to the total geographic area of the grid element; and 6) the geographic area of the grid element. In the hard disk version of DECON, SITEDB.DAT is on the default drive. In the floppy disk version, the default drive is drive A: and SITEDB.DAT is read from drive B:.

APPENDIX E

PREPARATION OF THE SITE DATA BASE

Three programs are used in preparing the site data base so that the data can be used directly by DECON. These are 1) the dose model, 2) the grid model, and 3) the site data model. They have the following functions:

- The dose model transforms CRAC2 ground concentrations into dose rates and n-year dose commitments measured at specified distance intervals along the plume centerline

- The grid model, using inputs from the dose model, organizes the accident grid and generates dose rates and n-year dose commitments at the mid-point of each grid element that must be processed

- The site data model accepts data by political subdivision (township, county and/or state); it then 1) imputes corresponding values to the elements of the accident grid, and 2) tranforms areas by land use type into areas by surface type.

E.1 THE DOSE MODEL

The dose model is used to develop dose-related information that is used in DECON. Such information is required by DECON in 1) selecting the appropriate decontamination method to apply to a contaminated surface, 2) computing the dose avoided by relocating the resident population until decontamination has been completed, 3) computing dose to radiation workers, and 4) identifying the boundaries of the accident area within which monitoring and surveying activities need to be undertaken.

The dose model is based on mathematical models used in the CRAC2 computer program as defined in the Reactor Safety Study (USNRC 1975). Several time points and periods must be defined in carrying out the analysis. These include:

1. Initial release time, also referred to as time zero. This time is used as the basis for the weathering calculations using the CRAC2 weathering model.

2. The period of time--typically several days--over which monitoring data are gathered. This period is used as the basis for radionuclide inventory decay calculations. The term "monitoring time" is used to represent this time period.

3. The time at which the dose period is to begin, and referred to as the "dose starting time." It represents a time at which reoccupation of the site begins. This time is varied in the analysis to determine the optimum time for re-entry.

4. The time period over which the dose is to be integrated, also known as the "dose period. This period will normally be either one or seventy years.

Daughter contributions are considered for inhalation and external dose calculations. The reader is referred to Appendix VI of the Reactor Safety Study (USNRC 1975) for details.

E.2 THE GRID MODEL

The grid model performs several functions relating to organizing the accident grid. First, it reads in the smallest value of dose or dose commitment that will be required in the site restoration analysis; this is the value of the strictest cleanup standard considered. Using this value, the grid model determines the maximum number of grid sectors that must be processed. This number will depend upon the width of the plume relative to its downwind distance and the number of degrees of arc per sector. The CRAC2 grid is divided into 16 sectors, each of 22-1/2^{o}. Typically, the maximum number of sectors required with this grid is three or five for a wide range of cleanup standards.

The next step is to determine how many distance intervals must be processed; i.e., how far from the release point the analysis must extend. Having thus bounded the problem latitudinally and longitudinally, the grid model then numbers each grid element within the bounded area sequentially. The numbering scheme was illustrated in Figure 5.1. This numbering scheme will provide the order in which DECON processes the grid elements.

The final step is to compute doses or dose commitments for each grid element. To do this, the grid model must be able to estimate dose at any location downwind from the release point but off the plume centerline. This is accomplished as follows: CRAC2 is run to produce a file of ground concentrations along the plume centerline at each of several downwind distances. At each distance interval, the plume is assumed to have a Gaussian distribution taken orthogonally to the centerline. The mean of the distribution is, of course, at the centerline, and the standard deviation is denoted by σ_y. The dose model transforms this information on ground concentrations into corresponding information on dose or dose commitment. Using trigonometric relationships, the grid model computes the dose or dose commitment at the center of each numbered grid element based on the Gaussian distribution value, σ_y, and the dose or dose commitment at the corresponding point on the centerline.

E.3 SITE DATA MODEL

As already noted, the site data model performs two basic functions. First, it takes information based on political subdivisions and develops comparable information for each grid element. Secondly, it tranforms areas by land use type into areas by surface type. The techniques for accomplishing these functions are described in this section.

E.3.1 Imputing Data Values to Grid Elements

In this section we describe the methodology for mapping county-based data onto a radial grid. A typical CRAC2 accident grid was illustrated in Figure 3.1 on page 3.2. The first step in generating the data base for the accident grid is to superimpose the accident grid on a map showing the boundaries of the political subdivisions. Ideally, township data should be used within 40 to 50 miles of the release point. County and even state data can be used at points further away. Each area element of the grid is then associated with the political subdivisions included within its boundary lines; specifically, the proportion of the area element in each of the political subdivisions is estimated. Call these proportions w_{ij}, where there are i political subdivisions and j grid elements. It is clear that

$$\sum_{i=1}^{I} w_{ij} = 1.0 \quad \text{for all } j$$

Other data that are presumed to be available for the analysis are:

$A_{\cdot j}$ = the land area in grid element j
$A_{i\cdot}$ = the land area in political subdivision i
$P_{\cdot j}$ = the population in grid element j
$P_{i\cdot}$ = the population in political subdivision i
$d_{i\cdot l}$ = the fraction of area in political subdivision i that is in land use l,=1,...,L.

In $d_{i\cdot l}$, let the first r of the l land use categories represent residential uses. These may include single-family, multi-family, mobile homes, etc.

The land area, $A_{\cdot j}$, and the population, $P_{\cdot j}$, are the only accurate information that is available for grid elements. This information is to be used to adapt the political subdivision information to the accident grid.

In the next step, we determine how much land is used for residential purposes in each grid element. Acreage in residential use in political subdivision i is given by

$$\overline{RA}_{i\cdot} = A_{i\cdot} \sum_{l=1}^{r} d_{i\cdot l}$$

Using the weights w_{ij} defined earlier, we determine the <u>expected</u> residential acreage in grid element j from

$$RA_{\cdot j} = \sum_{i=1}^{I} w_{ij}\, RA_{i\cdot}$$

A more direct estimate of the residential acreage in grid element j can be obtained by using the actual population in grid element j, and assuming that the population density per residential acre is a weighted sum of the densities in the individual political subdivisions. That is,

$$RA^*_{\cdot j} = P_{\cdot j} \sum_{i=1}^{I} w_{ij} \frac{P_{i\cdot}}{RA_{i\cdot}}$$

This second estimate, $RA^*_{\cdot j}$, will usually be a more accurate estimate of the residential acreage in grid element j. Therefore, we will use this estimate to adjust the estimates of other land uses in grid element j.

Although it seems reasonable to assume that commercial and, to a lesser extent, industrial activity are positively correlated with residential density (except in very small area elements), we have assumed in the current version of the site data model that intercorrelations among land use types are zero. Therefore, the difference between the two estimates of residential acreage, $RA_{\cdot j}$ and $RA^*_{\cdot j}$, will be spread proportionately among the other land use categories as follows:

$$\text{Let } \Delta_{\cdot j} = \frac{A_{\cdot j} - RA^*_{\cdot j}}{A_{\cdot j} - RA_{\cdot j}}$$

$\Delta_{\cdot j}$ is the factor by which nonresidential land uses must be increased or decreased within political subdivision j to compensate for "unexpected" excesses or deficiences in residential land use within the grid element. The unadjusted, expected land use in nonresidential categories is

$$A_{\cdot j} \sum_{i=1}^{I} w_{ij} d_{i\cdot l} \qquad (l=r+1,\ldots,L)$$

The adjusted, expected land use is

$$L_{jl} = \Delta_{\cdot j}\, A_{\cdot j} \sum_{i=1}^{I} w_{ij} d_{i\cdot l} \qquad (l=r+1,\ldots,L)$$

The last step is to transform the land use information developed for each grid element j into surface type information, since only the latter are compatible with decontamination procedures. This is described in Section E.3.2.

The site data model must also transform property value information to the accident grid. The current version of this model requires only an estimate of the market value of taxable property within each political subdivision. Reasonably recent estimates are available from (Census of Governments, 1978).

If $V_{i\cdot}$ is the market value of taxable property within political subdivision i, then the market value of taxable property within grid element j can be estimated from

$$V_{\cdot j} = \sum_{i=1}^{I} w_{ij} V_{i\cdot}$$

(Census of Government, 1978) gives the ratio of the value of all property to taxable property as 1.95. Then the value of all property within grid element j is estimated by

$$\overline{V}_{\cdot j} = 1.95 \, V_{\cdot j}$$

Currently available data bases provide information from which it might be possible to develop stable relationships for relating property values directly to land use categories. This would allow the decision module within the program DECON to behave more realistically in making decontamination/interdiction decisions.

E.3.2 Transformation of Land Uses into Surface Types

In this section, we describe the basis for transforming land using data into data relating to surfaces. The approach that is used is to divide the area to be decontaminated into a number of surface types.

E.3.2.1 Land Use Categories Currently Implemented

Currently, ten different land use categories are implemented by DECON; they are reported in Table E.3.1. With the notable exception of wet areas, these land uses are expected to encompass all of the major land uses found around reactors. Wet areas have not been researched to determine what decontamination procedures are applicable and under what circumstances. In addition to these ten land use types, DECON also has the capability of addressing the decontamination of automobiles.

TABLE E.3.1. Land Uses Currently Implemented

1. Residential	6. Parking Lots
2. Commercial	7. Grain Crops
3. Industrial	8. Vegetable Crops
4. Streets and Roads	9. Orchards
5. Wooded Areas	10. Vacant Land

Another important category of property that has not been addressed is building contents. Thus, household furnishings and personal belongings in residences, and furnishings, fixtures, records, raw materials, inventory, machinery and equipment in commercial and industrial buildings have not been treated in our analysis.

E.3.2.2 Relationship of Land Use to Surface Type

It is convenient to utilize land use information to characterize the areas that need to be decontaminated. Such information has the virtues 1) of being site-specific; 2) of being readily available from state and local government agencies in most areas; and, most importantly, 3) of being adaptable to a decontamination analysis framework.

With regard to the actual application of decontamination techniques to property, however, it is more precise to consider the treatment of specific physical surfaces rather than of land use types. The decontamination of plaster walls, linoleum floors and asphalt roofs lends an accuracy to the analysis that is lost in the more general concept of decontaminating residential property. To proceed along these lines, it is necessary to provide the linkage between land use types and surface types. The surface types currently implemented by DECON are presented in Table E.3.2.

The following discussion documents PNL's development of the relationship between land use types and surfaces. The estimates that have been developed are based on land use and surface relationships that are believed to be widely representative. The relationships have been incorporated within a subroutine used in the site data model, which prepares the site database used in DECON. This subroutine, called XFORM, has been structured so that it is a simple matter to alter these relationships either because better general information has become available or because the analyst wishes to exploit available information relating to a specific study area.

TABLE E.3.2. Surface Types Currently Implemented by DECON

1.	Agricultural Fields	12.	Interior Walls, Brick
2.	Orchards	13.	Streets and Roads, Asphalt
3.	Vacant Land	14.	Streets and Roads, Concrete
4.	Wooded Land	15.	Roofs
5.	Exterior Walls, Wood	16.	Lawns
6.	Exterior Walls, Brick	17.	Auto Exteriors
7.	Floors, Linoleum	18.	Auto Interiors
8.	Floors, Wood	19.	Auto Tires
9.	Floors, Carpeted	20.	Auto Engine and Drive Train
10.	Floors, Concrete	21.	Other Paved Surfaces, Asphalt
11.	Interior Walls, Painted	22.	Other Paved Surfaces, Concrete

E.3.2.2.1 Methodology. For several of the land use types there is a one-to-one correspondence between land use type and surface type. For example, the orchard land use type is entirely equivalent to the orchard surface type. This equivalence relationship also exists for vacant land and wooded land.

Other land use types, such as streets and roads are broken down into just two surfaces: asphalt and concrete streets and roads. However, for some land uses, there are several different constituent surfaces. This is especially true for land use types which contain structures. These are residential, commercial and industrial areas. The presence of buildings means that not only are there more surface types, but because of vertical walls and multiple floors, total surface area is not equal to but greater than the area of the land use type.

Subroutine XFORM uses a similar methodology for residential, commercial and industrial areas. Conceptually, there are three basic steps in this methodology, though these are often combined in the actual calculation. The first step is to disaggregate the total land area into its horizontal components. For residential, commercial and industrial property these components generally include roofs, lawns, asphalt and concrete pavement and vacant land. Because roofs may overhang the structure, or because multi-layered open-air parking garages may be present, total horizontal exterior surface area may exceed the corresponding land area somewhat.

After estimating the relative areas of the horizontal exterior surfaces, the second step involves specifying the basic dimensions for a representative structure within that land use area. The most important of these dimensions is roof area since the other dimensions of the structure are specified as a proportion of the roof area. In this way, the surface area of interior walls, exterior walls, floors and basements are all derived.

In the third step, the percentage of wall and floor areas covered by different materials is specified. Thus, total floor area is apportioned among the various floor surface materials: linoleum, carpet, wood, or concrete. Due to resource constraints, not all types of surfaces have been addressed. For example, ceramic tile floors and exterior walls of aluminum siding are surfaces that have not been included.

This methodology and the factors to be estimated are described more explicitly by the equations in Table E.3.3. The term LUA denotes land use area and represents the area of residential, commercial, or industrial land under consideration. The upper case subscripted S's stand for the different surface types being estimated, while the lower case letters refer to factors that are to be estimated. These factors serve to define the relationships between surface areas and land use types. The definitions of these factors are given in Table E.3.4, and the specific estimates developed for these factors are shown in Table E.3.5. The discussion of how these estimates were developed is presented in Section E.3.2.2.2. The remainder of this section is devoted to explaining the meaning of the equations in Table E.3.3.

The first seven equations in Table E.3.3 deal with horizontal, exterior surfaces. Factors a through g represent simple fractions of the total land use area. Note, however, that these factors do not necessarily sum to unity for any particular area. The reason is that such things as overhanging roof eaves and multi-storied open-air parking garages may make the total horizontal exterior surface area greater than the corresponding land area. Note also that not all land use types are comprised of all of the surface types. For example,

TABLE E.3.3. General Methodology Used in Subroutine XFORM

Surface	Equation	
Roof	$S_{15} = a \times LUA$	1.1
Asphalt road	$S_{13} = b \times LUA$	1.2
Concrete road	$S_{14} = c \times LUA$	1.3
Other asphalt	$S_{23} = d \times LUA$	1.4
Other concrete	$S_{24} = e \times LUA$	1.5
Lawn	$S_{16} = f \times LUA$	1.6
Vacant	$S_{3} = g \times LUA$	1.7
Exterior concrete, brick wall	$S_{6} = i \times h \times S_{15}$	1.8
Exterior wood wall	$S_{5} = j \times h \times S_{15}$	1.9
Linoleum floor	$S_{7} = (n \times k + r \times m \times l)\ S_{15}$	1.10
Wood floor	$S_{8} = (o \times k + s \times m \times l)\ S_{15}$	1.11
Carpeted floor	$S_{9} = (p \times k + t \times m \times l)\ S_{15}$	1.12
Concrete floor	$S_{10} = (q \times k + u \times m \times l)\ S_{15}$	1.13
Painted wood, plaster interior wall	$S_{11} = (x \times v + z \times w \times l)\ S_{15}$	1.14
Interior concrete wall	$S_{12} = (y \times v + a' \times w \times l)\ S_{15}$	1.15

TABLE E.3.4. Factors and Definitions for Subroutine XFORM

Factor	Definition
a	ratio of roof area to land use area
b	ratio of asphalt road area to land use area
c	ratio of concrete road
d	ratio of other asphalt area to land use area
e	ratio of other concrete area to land use area
f	ratio of lawn area to land use area
g	ratio of vacant area to land use area
h	ratio of exterior wall area to roof area
i	fraction of exterior walls that are concrete or brick
j	fraction of exterior walls that are painted wood
k	ratio of floor area to roof area
l	fraction of buildings with basements
m	ratio of basement floor area to roof area
n	fraction of floor area that is linoleum
o	fraction of floor area that is wood
p	fraction of floor area that is carpeted
q	fraction of floor area that is concrete
r	fraction of basement floor area that is linoleum
s	fraction of basement floor area that is wood
t	fraction of basement floor area that is carpeted
u	fraction of basement floor area that is concrete
v	ratio of interior wall area to roof area
w	ratio of basement wall area to roof area
x	fraction of interior wall area that is painted wood or plaster
y	fraction of interior wall area that is concrete
z	fraction of basement wall area that is painted wood or plaster
a'	fraction of basement wall area that is concrete

by definition residential areas exclude roads since that is a separate land use type. However, commercial and industrial areas contain large paved areas such as parking lots. These large paved areas are treated in the same way as either concrete or asphalt roads. The categories "other paved surfaces, asphalt" and "other paved surfaces, concrete" refer to smaller exterior paved areas, such as patios, driveways and car port floors, which are not generally amenable to the high production rate decontamination techniques that can be applied to roadways.

As we have already noted, the estimation of roof area is especially important because it is used in essentially all of the remaining equations. Equations 1.8 and 1.9 are an example. They generate exterior concrete and painted wood wall surface areas. Factor h represents the ratio of total exterior wall area to roof area, and factors i and j further break down exterior wall area into concrete and painted wood surfaces.

Equations 1.10 through 1.13 deal with floor surfaces. These equations are not quite as simple as the exterior-wall equations. The primary reason for

TABLE E.3.5. Factor Estimates by Land Use Type

Factor	Residential	Commercial	Industrial
a	0.26	0.70	0.27
b	0.00	0.20	0.25
c	0.00	0.13	0.13
d	0.01	0.00	0.00
e	0.04	0.00	0.00
f	0.70	0.00	0.02
g	0.00	0.00	0.33
h	1.58	1.20	1.14
i	0.15	1.00	1.00
j	0.85	0.00	0.00
k	1.33	1.80	1.60
l	0.48	0.40	0.00
m	0.70	0.90	0.00
n	0.20	0.54	0.15
o	0.25	0.00	0.00
p	0.55	0.24	0.05
q	0.00	0.22	0.80
r	0.17	0.20	0.00
s	0.01	0.00	0.00
t	0.02	0.00	0.00
u	0.80	0.80	0.00
v	2.40	2.22	2.00
w	0.96	1.10	0.00
x	1.00	1.00	0.45
y	0.00	0.00	0.55
z	0.05	0.20	0.00
a'	0.95	0.80	0.00

this is that two types of floors are explicitly estimated: nonbasement floors and basement floors. Factor k represents the ratio of nonbasement floor area to roof area. In other words, k is approximately the average number of floors per structure. The factor preceding k in the equations is the proportion of nonbasement floor that is comprised of linoleum (n), wood (o), carpet (p), or concrete (q). The nonbasement floor surfaces are added to the basement floor surfaces as indicated by the addition within the parentheses. The three terms on the right side of the plus sign refer to basement floor surfaces. The factor l represents the proportion of homes that have basements. The factor m is the ratio of basement floor area to roof area. The factors r, s, t, and u are the fractions of basement floors that are covered with the four materials listed.

Equations 1.14 and 1.15 estimate the area of concrete and painted wood or plaster interior wall surfaces. The structure of these equations is analogous to the floor equations. Factor v is the ratio of interior wall area to roof area, and factor w is the ratio of basement wall area to roof area. Factors x, y, z, and a' indicate the proportions of wall area constructed of concrete or painted wood and plaster.

The methodology embodied in these equations is intended to be general. That is, should the user wish to add other land use types, these equations may be directly applicable for generating surface area estimates, once the factor values for the new land use type have been determined.

E.3.2.2.2 Estimation of Factors. In this section the derivation of the factor estimates is described and principle information sources are provided. The discussion of the factor estimates generally follows the surface area estimating methodology. That is, the first step is to determine the exterior, horizontal surface factors. Then, based on the dimensions of a representative structure for that land use type, the exterior wall area, interior wall area, and floor areas are estimated as proportions of the roof area. These surfaces are then subdivided into the specific materials with which they are constructed or covered. For example, once the floor area factor is estimated it is necessary to estimate the proportion which is linoleum, wood, concrete, or carpeted. Finally, the factors for surfaces associated with basements are estimated.

It is important to note two important facts regarding the residential area factor estimates. First, data for estimating the factors are extremely limited, and much of the data which are available provide only indirect information about the factors. Second, the intent of these estimates is to characterize the surface makeup of representative residential, commercial, and industrial areas. For each of these land use categories there is a very wide variance in construction techniques, land cover, materials, and so forth. Therefore, true factor values for any particular area could differ greatly from the estimates developed here. This suggests that where such differences are large it may be desirable to specify alternate values for these factors.

Both of these difficulties could be addressed at least to the extent of identifying exterior surfaces for any particular area by the use of high-quality aerial photos combined with standard manual or automated aerial reconnaissance techniques. By determining building dimensions and density, it may also be possible to refine estimates of factors for interior surfaces. Such photos are sometimes available from the United States Geological Survey or from local municipalities, where they are used for zoning, planning, and mapping purposes. In fact, the NRC already has a set of high-quality aerial photos (transparencies and prints) covering the vicinity around approximately 60 reactor sites. There is one photo per site, and each covers a square area about 11.5 miles on a side. With good equipment, the transparencies can be used to identify features less than one square meter in size. Also, they could be scanned and digitized for computer storage and analysis. A major reactor accident, however, could affect areas significantly further away than 11.5 miles from the reactor site.

Residential Areas. Residential land use areas in this work refer to areas comprised of single-family detached homes and excluding public roads, vacant land and wooded areas. Apartments are included in commercial land use areas. Other residential types, such as single-family attached and mobile homes, have not yet been addressed.

To be considered first are the factors defining the exterior horizontal surface areas (roof, lawn, other concrete, and other asphalt). A guide for determining the share of residential land covered by lawn lies in several studies prepared for various locations concerned with rain water runoff. In analyzing the amount, rate, and pollution of runoff, these studies generally estimate the percentage of land cover which is "impervious". Impervious cover includes houses, sidewalks, roads, parking lots, and other surfaces which prevent rainfall from penetrating into the soil. The principal surface not included in this group is lawn. Thus, we can assume that, after some adjustments to the data, any residential surface that is not impervious is lawn.

The United States Geological Survey provided sections of a number of these runoff studies, each of which deals with several drainage areas within a specific city or urban area. There is no study that identifies the percentage of impervious cover for all residential areas in the United States. Further, the locales for these investigations were not selected with any intent to be representative of any particular land use type. This means that these data can only give an indication of the range and variability of $\underline{f}$, the ratio of lawn area to total area.

Table E.3.6 presents data from these reports that are relevant for estimating lawn cover in residential areas. Note that the drainage areas in the runoff reports are not strictly residential according to the designations used in this work. In particular, impervious area in the runoff reports includes road surfaces, and some reports noted proportions of the drainage area that are commercial, industrial, or other use type.

The Pompano Beach, Florida, site characteristics provide sufficient information to make a rough estimate of how much the given impervious percentage should be adjusted to remove road surface area. Assuming a street width of 25 feet, which appears reasonable from the aerial photo in the report, then each lot, including its share of the street, measures about 92.5 feet by 100 feet, making a total of 9250 square feet per lot. Since 43.9 percent is designated impervious, that is equivalent to about 4060 square feet. Of this area, the street comprises an area of about 12.5 by 80 feet, an area of 1000 square feet. Thus, the impervious nonstreet area per parcel is about 3060 square feet, or 33 percent of the nonstreet residential area. Another way of looking at this is that about 10 percent of the land (or 25 percent of the reported impervious area) is road pavement. The impervious cover estimate is adjusted for road surfaces by subtracting 10 percent from the figure given.

In addition, some site descriptions include information on the amount of vacant land and other characteristics. Assuming that open land, parks, public land, conservational land, agricultural land, and so forth are all pervious surfaces, the pervious-impervious estimate for residential areas can be further improved. The fifth column of Table E.3.6 shows the impervious area percentage after taking into account the adjustment for road surface and this last adjustment for vacant land. However, no adjustment was made for industrial and commercial areas since their surface composition (pervious or impervious) was not known. By subtracting these adjusted impervious area figures from 100, an estimate of lawn area was obtained. These estimates are listed in the last

TABLE E.3.6. Selected Data from Runoff Reports

Source	Site	Site Characteristics		Impervious Area (%)	Adjusted Impervious Area (%)	Estimated Lawn Area (%)
"Effects of Storm Runoff on Water Quality in the Mill Creek Drainage basin, Willingboro, New Jersey"	W1, W2, W4, W5, W9	Single-family residential	= 56.25%	24.70	25.0	75.0
		Multi-family residential	= 0.0%			
		Commercial	= 0.50%			
		Industrial	= 12.10%			
		Public, conservational, recreational	= 31.15%			
"Quantity and Quality of Urban Runoff from the Denver Metropolitan Area, Colorado"	Littleton	Single-family residential	= 75%	25	23.1	76.9
		Parks and open space	= 25%			
	Lakewood	Multi-family residential	= 30%	40	75.0	25.0
		Commercial	= 20%			
		Undeveloped	= 50%			
	Denver	Mixed single- multi-family res.	= 37%	65	65.5	34.5
		Multi-family	= 37%			
		Commercial	= 20%			
		Parks	= 6%			
"Urban Storm-Water-Quality Data Portland, Oregon, and Vicinity"	Fanno Creek	Single-family residential	= 76%	32	28.2	71.8
		Multi-family residential	= 6%			
		Commercial	= 6%			
		Rural	= 12%			
	Willamette R. tributary in Oak Grove	Single-family residential	= 73%	36	34.7	65.3
		Multi-family residential	= 4%			
		Commercial	= 8%			
		Rural	= 15%			

Source	Site	Site Characteristics						Impervious Area (%)	Adjusted Impervious Area (%)	Estimated Lawn Area (%)
	Tyron Creek	Single-family residential = 72% Multi-family residential = 10% Commercial = 5% Rural = 13%						32	28.6	71.4
"Storm Runoff As Related to Urbanization in the Portland, Oregon-Vancouver, Washington Area"		A	B	C	D	E	F *			
	Vancouver sewer outfall	25	0	13	36	21	5	49	60.0	40.0
	Beaverton Creek	25	3	51	4	13	4	23	21.0	79.0
	Fanno Creek	13	0	75	6	6	0	32	28.6	71.4
	Singer Creek	18	0	77	4	1	0	28	25.0	75.0
	Willamette River Tributary (Oak Grove)	14	0	74	4	8	0	36	34.2	65.8
	Tyron Creek Tributary	12	0	72	11	5	0	32	28.2	71.8
	NE Hancock-Flint sewer	2	0	0	91	5	2	43	37.5	62.5

Source	Site	Site Characteristics						Impervious Area (%)	Adjusted Impervious Area (%)	Estimated Lawn Area (%)
		A	B	C	D	E	F *			
	N Albina-Kilpatrick sewer	6	0	1	75	18	0	44	40.5	59.5
	N Vancouver-OWR&N sewer	2	0	0	81	17	0	46	40.9	59.1
"Characteristics of Four Urbanized Basins in South Florida"	Pompano Beach, Broward Co., FL	Land use: single-family residential Average lot size: 80' x 100' Average house size: 40' x 60'						43.9	32.9	67.1
	Kings Creek Apts., So. Miami, FL	Land use: apartments						70.7	53.0	47.0
"Bellevue Urban Runoff Project and Bellevue Street Sweeping Demonstration Project"	Surrey Downs	Single-family homes and a senior high school						35.0	26.3	73.7
	Lake Hills	Single-family homes and church						43.1	32.3	67.7

Source	Site	Site Characteristics	Impervious Area (%)	Adjusted Impervious Area (%)	Estimated Lawn Area (%)
"Quality of Runoff From Small Watersheds in the Twin Cities Metropolitan Area, Minnesota--Hydrologic Data for 1980	80th St. storm sewer	Fully developed medium-density residential	16.0	7.6	92.4
	Estates Drive	Medium- to high-density single-family residential	29.0	21.8	78.2
	Highway 100	High-density single-family with intersection commercial	35.0	26.3	73.7
	Valley View Road	Medium-density single- and multi-family	11.0	8.3	91.7

*A = Parks, forests, vacant
B = Agricultural
C = Light to normal residential
D = Dense residential
E = Apartments and commercial
F = Downtown and industrial

column of Table E.3.6. The figures show that there is considerable variability in surface makeup of residential property, with estimates of lawn area ranging from a low of 25 percent to a high of 92.4 percent.

Another source of information was provided by the City of Bellevue, Washington, Storm and Surface Water Utility Department, in the form of a large aerial photograph of a residential area with a corresponding map of properties and structures. A random sample of surfaces was taken from the photograph. The quality of the photograph was such that it was impossible to distinguish asphalt from concrete. Therefore, driveways and other paved surfaces were assumed to be concrete. In general, the neigborhood in the photograph appeared to be a fairly new subdivision with larger than average lots and homes. The proportion of lot coverage by the house is probably less than average for urban residential areas.

After excluding observations that happened to land on nonresidential areas such as roads, the results are in Table E.3.7.

TABLE E.3.7. Percentage of Residential Land in Roofs, Lawns and Concrete

Surface	Percent
Roof	22.3
Other concrete	9.6
Lawn	68.1

The factor estimates are summarized in Table E.3.8; they are based on all the foregoing information and on the assumption that 80 percent of nonroad pavement is concrete. The factors total more than unity becase of assumed roof overhangs.

The remaining factors are based on the dimensions of a hypothetical representative house. The two basic measures needed are the average floor

TABLE E.3.8. Summary of Factors for Horizontal, Exterior Residential Surfaces

Factor	Definition	Value
a	Ratio of roof area to residential land area	0.26
d	Ratio of other asphalt area to residential land area	0.01
e	Ratio of other concrete area to residential land area	0.04
f	Raio of lawn area to residential land area	0.70

space and the average number of floors per home. The number of floors is particularly important for determing the height and, therefore, the area of the exterior walls. The 1980-82 Statistical Abstract reports that the average number of square feet per household is 1745. According to the Census Bureau and the U.S. Department of Housing and Urban Development, the median-sized home built in 1982 has 1520 square feet of floor space. This was less than in 1980, when the median size was 1550 square feet. While this work is concerned primarily with detached single-family homes, it can be noted that the median-sized apartment built in 1982 contained 925 square feet, compared with 930 square feet in 1981. In general, the typical home seems to be about 1500 to 1700 square feet. Here, a size of 1600 square feet is used.

The National Association of Home Builders provided the information that of the homes completed in 1982, 61 percent were single story, 33 percent were two or more stories, and 6 percent were split level. Assuming that these 1982 figures are not greatly different from those for the housing stock, a weighted average number of floors per house is calculated as follows: Split-level homes are considered to be one story, and homes designated as two or more stories are assumed to be 2.2 stories on average. The relationships for computing the weighted average number of floors are presented in Table E.3.9.

TABLE E.3.9. Computation of Number of Floors per Average Single-Family Residence

	Percentage Weight	x	Number of Floors	=	Product
	61		1		61
	33		2.2		72.6
	6		1		6
Total	100				139.6

Average number of floors = 139.6/100 = 1.4

Given a total floor area of 1600 square feet over 1.4 floors, the roof area is:

Roof area = 1600/1.4 = 1143 square feet

This figure is adjusted up to 1200 square feet to account for overhanging eaves. The factor $\underline{k}$, the ratio of nonbasement floor area to roof area, then becomes

$k = 1600/1200 = 1.33$

The roof with eaves covers 1200 square feet, but without the eaves the area is approximately 1140 square feet. This is consistent with exterior building dimensions of 38 by 30 feet. The total building perimeter is, then, 136 feet. Assuming 10 feet per story, the average exterior wall height is 10 x 1.4 = 14 feet. The total exterior wall area is, therefore, 14 x 136 = 1904 square feet. Factor $\underline{h}$, the ratio of exterior wall area to roof area, becomes

$h = 1904/1200 = 1.58$

To estimate v, the ratio of interior wall area to roof area, we note first that according to the Census Bureau the average number of rooms per home is 5.1. With a total floor area of 1600 square feet, the area per room is 313.7. The minimum wall length for such a room is about 17.7 feet. If each room has four walls 8 feet high, then total wall area is 2890 square feet. This estimate will be low to the extent that rooms depart from square dimensions and to the extent that closets and hallways are additional to the 5.1 rooms. On the other hand, the estimate could be too high if doorways are large and if there are half walls. Factor v is

$$v = 2890/1200 = 2.40$$

Next we consider basements, focusing first on factor l, the fraction of homes that have basements. The National Association of Home Builders, in the September 1983 Housing Backgrounder, lists the percentage of new single-family homes built with basements by year. This information is presented in Table E.3.10.

TABLE E.3.10. Percentage of Houses with Basements, by Year

	1972	1977	1978	1979	1980	1981	1982
Houses with full or partial basements	37%	44%	42%	42%	36%	33%	31%

The source of the figures in Table E.3.10 is apparently either the Census Bureau or the U.S. Department of Housing and Urban Development. Reference to the 1970 Census of Housing, Vol. 1, Part 1, Table 22, gives additional information about numbers of housing units with basements by region. This is presented in Table E.3.11. These regional figures might serve as a guide for any adjustments to factor l. Based on the preceding information, 0.48 seems to be an acceptable estimate for l.

Factor m represents the size of the basement in relation to roof area. Here we have no firm data and are forced to estimate average basement floor area at 0.70 times the roof area. If the basement has a single room with 8-foot walls, then factor w, the ratio of basement wall area to roof area, is about 0.96.

This completes the estimates of the structure surface areas, but now these must be further disaggregated by type of material. For this task there appears to be little or no government-collected data. What data do exist are generally

TABLE E.3.11. Number of Houses with Basements, by Region

	Region				
	U.S.	North East	North Central	South	West
Basement	36,112,009	14,398,977	14,141,653	4,407,897	3,163,482
Concrete slab	14,358,800	1,040,632	1,971,873	6,668,107	4,678,188
Other	17,228,275	758,253	2,561,706	9,807,562	4,100,754

Source: 1970 Census of Housing, Vol. 1, Part 1, Table 22

commercial marketing data. There are usually two drawbacks to this information. First, since it is proprietary, many sources are very reluctant to release it. Second, companies are most often concerned with current sales figures rather than accumulated existing stock. For example, businesses dealing with floor covering materials are less interested in the percentage of total floor area that is carpeted than in the percentage of current sales of floor covering materials accounted for by carpeting.

Roofs of single-family homes are assumed to be of asphalt shingles. This is based on casual observation and on a listing of building materials for a typical 1700 square foot home in the National Association of Home Builders' September 1983 Housing Backgrounder.

In this report we assume that exterior walls of single-family residences are either brick or painted wood. There is apparently no direct quantitative information on the relative usage of brick versus wood siding. The Brick Institute of America did report that 8 to 9 billion bricks per year are sold and, of those, 65 percent are used in single- and multi-family home construction. It is not clear, however, how much of this goes to exterior wall construction. Of the total brick sales, only about 600 million bricks--less than one-tenth of the total--are used west of the Rocky Mountains. This is due in large part to brick's incompatibility with the earthquake hazard. We estimate that 15 percent of exterior walls are brick; the remainder are assumed to be painted wood.

Nonbasement floors are assumed to consist of either wood, linoleum (all resilient floor coverings), or carpet. The floor covering industry seems to be particularly protective of marketing information. However, the Retail Floorcovering Institute did provide its 1983 Management Report. The sales profile data list percentage of sales by type of customer (e.g., residential, contractor, industrial/commercial). Also listed was percentage of sales by product type. Soft surface (carpet) comprised 74.9 percent of sales. Sheet vinyl and resilient tile together accounted for 13.1 percent of sales. Hardwood flooring made up 1.2 percent of sales. Also listed in this publication was the average price per square yard of soft surface products (carpets) sold on a retail basis ($15.66) and the average price per square yard for hard surface products sold on a retail basis ($20.00). To obtain an idea of the relative areas for different kinds of surfaces, we compare the ratio of percentage of sales to the average cost per yard for both hard and soft surfaces. Total carpet area sold was roughly six times the total hard surface area sold. Hard surfaces include wood, ceramic tile, and resilient floor coverings. Total sales in this group are dominated by sheet vinyl. This material accounts for about two-thirds of sales. Hardwood flooring, considering that its price is much greater than sheet vinyl, accounts for less than one-tenth of the area of vinyl.

Additional information comes from a representative of the Wood and Synthetic Flooring Institute. He estimated that in existing homes wood floors were the second most common following carpeted floors. Vinyl surfaces were third. However, he had no quantitative data to indicate the relative shares of these materials. He also provided information about regional differences. In the South, especially in Florida, homes are often constructed on a concrete slab. These homes have no basements and very seldom have wood floors. In other areas, wood joist construction techniques are used. These homes more often have wood floors and basements. This suggests that the regional basement data provided above might be useful for adjusting the floor covering factors.

The fraction of floor surfaces that is linoleum (n) is estimated to be 0.20. The wood factor (o) is estimated at 0.25, and 0.55 is the estimate for the carpet factor (k_r).

All nonbasement interior walls are assumed to be painted wood or plaster, so no special factors applied to interior wall area are necessary. Similarly, basement floors and walls are assumed to be concrete.

As a final note, it should be mentioned that a potential source for data specific to a particular locale may be the local property tax assessment records. These records typically include such information as lot size, structure size, number of floors, number of rooms, construction material, driveway dimensions, and so forth. Unfortunately, this type of information is not normally available in machine-readable format, which would allow one to readily characterize a representative structure.

Commercial Areas. This section describes how the various factors for commercial areas were estimated. As with the factors for residential areas, the first to be estimated are those relating to horizontal, exterior surfaces. Then, factors specifying the dimensions of the representative commercial structure are developed. Finally, the factors dealing with the proportion of specific materials used for floor covering material are developed.

The lack of data for commercial land use areas is even more acute than for residential areas. This is compounded by an even greater variability in land use practices on commercial property compared with those on residential property. A simple example of this variability is illustrated by the fact that areas designated commercial include high-density downtown business areas, small arterial and neighborhood commercial areas, and large suburban shopping centers.

Exterior horizontal surfaces in commercial land use areas include roofs, asphalt parking areas and concrete parking areas. The various runoff reports described in Section E.3.2.2.2 do not help to identify these surfaces, since they are all categorized as "impervious".

The City of Bellevue, Washington supplied an aerial photograph and an accompanying map of a commercial area. However, this area is distinctly a low-density shopping center type and was not felt to be representative of commercial areas in general. The photograph did, however, give a guide as to the lower range for a, the ratio of roof area to commercial land area. Rough estimates place roof area at no higher than 50 percent of surface area. The low seems to be about 20 percent of land area. Average roof cover, then, would be expected to lie somewhere between 50 percent for low building density suburban shopping center areas and 90 percent or more for high building density downtown business areas. We take 70 percent to be representative.

Commercial areas include parking areas. While multi-level parking garages are generally constructed in concrete, street level parking surfaces are predominantly asphalt. Because street level parking lots comprise a larger share of parking surfaces, we estimate b_c, the ratio of asphalt road area to commercial land area, to be 0.20. Factor c, representing the ratio of concrete parking area to commercial land area is estimated at 0.13. The horizontal, exterior commercial surfaces add to more than unity to account for multi-level concrete parking garages.

Next to be considered are the dimensions of the representative commercial structure. Fortunately, some useful data relevant to this question are available. Of particular interest is Nonresidential Buildings Energy Consumption Survey: Building Characteristics by the U.S. Department of Energy. Table 3A in that publication provides information on numbers of commercial buildings by square footage and function. That information is reproduced here in Table E.3.12. These figures can be used to derive an estimate of the average square footage of commercial buildings. This is done by computing the weighted average floor area of all commercial buildings. To do this, the midpoint of the given size intervals was used except for the two end intervals. For these, values of 750 and 110,000 square feet were used. The calculations yielded an average commercial building size of 10,820 square feet. In addition to the overall average commercial building size, average building size for each separate function was also calculated (see Table E.3.13). These figures were used in developing the factor estimates relating to materials used for floor cover.

To obtain the gross exterior dimensions it was next necessary to estimate the number of floors in the representative commercial structure. Table 4A in the DOE publication cited above supplied information useful for this purpose. Figures from that table are presented here in Table E.3.14. The number of floors in the representative commercial building was computed as a weighted average of all types of commercial buildings. This was a straightforward use of the top row of Table E.3.14, except that for the last group, the number of floors was assumed to be 5.5. The result was 1.8 floors per building. Thus, k, the ratio of floor area to roof area, is 1.80.

TABLE E.3.12. Number of Commercial Buildings by Total Square Footage and Function (Numbers in Thousands)

Function	Total	Total Square Footage: 1,000 or less	1,001-5,000	5,001-10,000	10,000-25,000	25,001-50,000	50,001-100,000	Over 100,000
Total	3995	655	1672	745	551	207	101	65
Assembly	448	44	156	131	79	25	8	5
Auto sales and service	401	92	197	78	28	5	1	1
Education	161	10	33	21	31	30	24	13
Food sales	366	70	207	51	31	5	2	1
Health care	44	4	15	9	6	2	4	4
Lodging	101	10	33	22	16	13	4	3
Office	600	89	259	115	86	27	13	12
Residential	347	41	177	45	64	11	6	2
Retail/services	714	123	292	152	95	31	14	7
Warehouse and storage	430	79	169	59	64	33	17	10
Other	237	58	76	38	39	16	5	5
Vacant	147	37	59	24	12	9	2	2

Note: Data may not sum to totals due to rounding.
Source: U.S. Department of Energy, Nonresidential Buildings Energy Consumption Survey: Building Characteristics, March 1981, Table 3A, p. 13.

TABLE E.3.13. Mean Square Footage of Commercial Buildings by Function

Building Function	Mean Square Footage
All Commercial Buildings	10,820
Assembly	11,060
Auto sales and service	5,260
Education	32,060
Food sales	5,600
Health care	23,530
Lodging	16,520
Office	10,870
Residential	8,940
Retail/services	7,130
Other	11,660
Vacant	8,920

Dividing the total floor space by the number of floors gave 6000 square feet, which represents average roof area and average square footage per floor.

TABLE E.3.14. Number of Commercial Buildings by Number of Floors and Function (Numbers in Thousands)

Function	Total	1 Floor	2 Floors	3 Floors	More than 3 Floors
Total	3995	2322	912	483	279
Assembly	448	195	169	68	16
Auto sales and service	401	326	68	8	0
Education	161	86	41	22	13
Food sales	366	256	74	28	9
Health care	44	16	16	6	6
Lodging	101	44	28	13	16
Office	600	300	151	88	62
Residential	347	55	84	120	87
Retail/services	714	476	141	71	27
Warehouse and storage	430	310	74	30	15
Other	237	163	35	21	18
Vacant	146	96	33	7	10

Note: Data may not sum to totals due to rounding.
Source: U.S. Department of Energy, Nonresidential Buildings Energy Consumption Survey: Building Characteristics, March 1981, Table 4A, p. 16.

Approximate dimensions for such a building were assumed to be 55 by 110 feet. The exterior wall area was estimated by multiplying wall height per floor (say, 12 feet) by the average number of floors (1.8) by the total building perimeter (330 feet). This yielded 7130 square feet. The ratio of exterior wall area to roof area was

$$h = 7130/6000 = 1.20$$

Estimation of the percentage of commercial buildings with basements did not have the advantage of direct evidence. A rough approach was to determine a weighted average of buildings with basements by estimating the percentage of each commercial building function likely to have basements. In this procedure, 15 percent of both assembly and automotive sales/service were estimated to have basements. Twenty percent of education, 10 percent of food sales, and 90 percent of health-care structures were presumed to have basements. The corresponding figures for other commercial buildings were: lodging, 10 percent; office, 80 percent; residential, 70 percent; retail/services, 50 percent; and warehouse and storage, 10 percent. This procedure was felt to be an improvement over a single direct estimate of the fraction of commercial buildings with basements because it reflects the distribution of building functions. This weighted average calculation process disregarded the "other" and "vacant" categories. The result was that factor $\underline{l}$ was 0.40.

Given that a building has a basement, we estimate the size of the basement relative to roof area (m) at 0.90. Basements are presumed to be divided into four large rooms. With a height of 10 feet, basement wall area will be about 6600 square feet, making $\underline{w}$, the ratio of basement wall area to roof area, equal to 1.10.

Interior wall area will vary greatly from structure to structure. For example, buildings used for assembly, sales, and warehousing purposes will tend to have few but relatively large rooms. On the other hand, lodging buildings and most offices will have the floor segmented into more rooms of smaller size. In order to estimate $\underline{v}$, a hypothetical 55-foot by 110-foot floor plan was divided up into a number of large and small rooms. These rooms included one large one measuring 55 by 55 feet and several others of various smaller sizes. This yielded a total room perimeter of 740 feet per floor. With 1.8 floors per building and an average interior wall height of 10 feet, total interior wall area is 13,320 square feet. Thus, the ratio of interior wall area to roof area is

$$v = 13{,}320/6{,}000 = 2.22$$

Next to be considered are the materials with which the building walls and floors are constructed. Walls are assumed to be all painted wood or plaster. The factors for floor covering material are developed in Table E.3.15. It is possible to estimate reasonable percentages for different floor covering materials for commercial buildings when the building function is specified. These separate estimates are then multiplied by the aggregate square footage for buildings of that function. This yields the area for different floor covering material by building function. The total concrete, linoleum, and

TABLE E.3.15. Estimation of Floor Covering Material Factors

Building Function	Number of Buildings	Mean Square Footage	Estimated Floor Covering Percent: Concrete	Linoleum	Carpet	Floor Covering Area: Concrete	Linoleum	Carpet
Assembly	448	11,060	80	20	--	3,963,904	15,855,616	--
Auto sales/serv.	401	5,260	65	35	--	1,371,019	738,241	--
Education	161	32,060	10	80	10	516,166	4,129,328	516,166
Food sales	366	5,600	--	100	--	--	2,049,600	--
Health care	44	23,530	--	90	10	--	931,788	103,532
Lodging	101	16,520	--	5	95	--	83,426	1,585,094
Office	600	10,870	--	15	85	--	978,300	5,543,700
Residential	347	8,940	--	10	90	--	310,218	2,791,962
Retail/services	714	7,130	--	60	40	--	3,054,492	2,036,328
Warehouse, storage	430	13,350	100	--	--	5,740,500	--	--
Total	3,612	(a)				11,591,589	28,131,009	12,576,782
Factor						0.22	0.54	0.24

(a) Total square footage is 52,299,380.

carpeted floor area is calculated, and these totals are then divided by total floor area to yield the following factor estimates:

$q = 0.22$
$n = 0.54$
$p = 0.24$

Industrial Areas. As in the preceding two sections, the first factors to be estimated are those having to do with horizontal exterior surfaces. Following that, factors that characterize a representative industrial structure are derived. Finally, those factors that allocate surfaces among specific materials, such as floor area to wood, carpet, concrete, or linoleum material, are estimated.

The horizontal, exterior surfaces in industrial areas consist of roof, asphalt and concrete parking areas, and lawn surfaces. As with residential areas, a starting point could be the runoff studies summarized in Table E.3.6. These studies provide information on the percentage of particular drainage areas that are covered with impervious surfaces such as buildings or pavement. The remaining pervious area corresponds to the only pervious surface, lawn. Unfortunately, only two of the many drainage areas covered by these studies were characterized by a significantly high proportion of land in industrial use. In "Quality of Runoff From Small Watersheds in the Twin Cities Metropolitan Area, Minnesota - Hydrologic Data for 1980," the Sandburg Road site was described as a light industrial park with partly curbed or guttered streets. The area includes a school and a major industry parking lot. In this area, 5.8 percent of the land was designated as agricultural or idle, 9.6 percent as low-density homes, and 84.6 percent as commercial-industrial. The impervious area was listed as 70.0 percent. If this figure is adjusted by subtracting the agricultural portion from the 30 percent pervious area, we get 74.3 percent of the area as being impervious. In other words, 25.7 percent of the area is pervious lawn.

In "Storm Runoff As Related to Urbanization in the Portland, Oregon-Vancouver, Washington Area," the SE 9th-Madison site is listed as being 19 percent downtown and industrial. In this drainage area, 39 percent is denoted impervious. The remainder - 61 percent - therefore is lawn.

Another source of information is a large aerial photograph of an industrial area supplied by the Storm and Surface Water Utility Department of the City of Bellevue, Washington. As was done with the aerial photograph of a Bellevue residential area, the surfaces at randomly selected points were noted in order to establish an estimate of the relative distribution of exterior horizontal surfaces. However, unlike the residential area photograph in which essentially all of the photograph was of the one land use type, the industrial area photograph included a large proportion of undeveloped land. The sampling area was therefore restricted to the north side of Bellevue-Redmond Road. Within the remaining area there remained some undeveloped parcels. These too were excluded from the sample. The tonal quality of the photograph made it impossible to distinguish between concrete, asphalt, and vacant, except by inference from the use of, and objects on, the surface. In general, it was felt that little or no concrete was used in that area. In instances where the sample point landed on a vehicle or material in storage on the property, such as lumber, that fact was noted and the surface was recorded as either vacant or asphalt pavement. Also, as with the residential photo, public roads were eliminated from the sample because concrete and asphalt roads are a separate land use category. The results of the sampling process appear in Table E.3.16.

The foregoing information on horizontal, exterior surfaces is summarized in Table E.3.17. From this data we estimated the roof factor at 0.27. The

TABLE E.3.16. Sampling Results for Distribution of Industrial Surfaces

Surface	Percent
Asphalt or concrete road	47.9
Vacant	26.0
Roof	24.7
Lawn	1.4

TABLE E.3.17. Summary of Data on Horizontal Exterior Surfaces in Industrial Land Use Areas

	Surface				
Source	Roof	Asphalt Road	Concrete Road	Vacant	Lawn
Runoff Study #1		74.3%		25.7%	
Runoff Study #2		39.0%		61.0%	
Aerial Photo	24.7%	47.9%		26.0%	1.4%
Map	29.3%		70.7%		

data for asphalt and concrete road surfaces were not as clear. The sum of the roof percentage, plus the two pavement percentages in the first three sources, were 74.3, 39.0, and 72.6 percent, respectively, with an average of 62.0 percent. If we weight the 39.0 percent figure less than the other two in the averaging process - because it seems the most likely figure to be an outlier - a figure of 65.0 percent is obtained, which seems reasonable. Subtracting 27.0 percent for roof area leaves 38.0 percent for the total of asphalt and concrete areas designated as parking areas. The breakdown between these materials is unclear, though it is felt that asphalt will be used more for roads and parking lots while concrete will be used more often for other functions. In general, it is felt that in total, the asphalt area will be about twice that of concrete. Thus, the asphalt factor is estimated at 0.25 and the concrete factor at 0.13.

Accompanying the photograph was a map indicating for several parcels property lines, building outline, and property areas. This map provided enough information so that the building size could be determined by measurement. Thus, roof area as a proportion of lot area could be calculated. These calculations yielded roof area as a percentage of land area, ranging from a low of 15.2 percent to a high of 55.0 percent. The average of the properties measured was 29.3 percent.

The foregoing estimates constrain the estimates for the vacant land and lawn factors to sum to 0.35. We estimate lawn area at 2.0 percent of industrial areas and vacant land at 33.0 percent. These factors are summarized in Table E.3.18.

TABLE E.3.18. Distribution of Exterior, Horizontal Industrial Areas

Factor	Surface	Estimated Value
a	roof	0.27
b	asphalt road	0.25
c	concrete road	0.13
f	lawn	0.02
g	vacant	0.33

The next step is to estimate the dimensions of the representative industrial structure. For this purpose the U.S. Department of Energy publication Nonresidential Buildings Energy Consumption Survey: Building Characteristics is very helpful. Table 3A provides the following information on building square footage. These data are reproduced in Table E.3.19. An average building size was calculated using the same weighted average process described for commercial buildings, yielding a result of 22,400 square feet.

TABLE E.3.19. Numbers of Industrial Buildings by Total Square Footage (in Thousands)

Total	1000 sq. ft. or less	1,001-5,000 sq. ft.	5,001-10,000 sq. ft.	10,001-25,000 sq. ft.	25,001-50,000 sq. ft.	50,001-100,000 sq. ft.	Over 100,000 sq. ft.
243	22	58	55	45	30	20	13

Table 4A of the DOE publication listed the number of buildings having one, two, three, or more than three floors. Again, a weighted averaging process as for commercial buildings was used to find the average number of floors at 1.6. This is the value taken for factor k. Dividing total floor area by the number of floors gives an average 14,000 square feet per floor. This figure is also used as the estimate for roof area.

We assume building length and width of 165 by 85 feet with height of 20 feet per floor. With 1.6 floors, this makes the exterior building wall area equal to 16,000. The factor relating exterior wall area to roof area is, therefore:

$$h = 16,000/14,000 = 1.14$$

The factor for interior wall area was estimated by designing a hypothetical floor plan for a 165 by 85 foot industrial building. The interior walls in such a structure served to set off a small portion of the main floor area while leaving most of the interior open and unobstructed. This plan had a total of 910 linear feet of interior wall, compared with an exterior wall length of 500 feet. The factor relating interior wall area to roof area (v) is 2.00. It is assumed that industrial structures do not have basements.

Exterior walls and interior walls along the perimeter of the building are assumed to be of brick or concrete construction. The remaining interior walls are assumed to be painted wood or plaster. Based on the interior wall dimensions described above, x, the fraction of interior wall area that is painted wood or plaster, is 0.45, and o_i, the factor for concrete walls, is 0.55.

A representative of the Wood and Synthetic Flooring Institute said that there were no data on industrial floor materials. However, he indicated that concrete was the material in greatest usage with a synthetic resilient flooring the second most common. Carpet would be used in some of the office space. We estimate the factor for concrete floor (q) at 0.80, and 0.15 and 0.05 for linoleum (n) and carpet (p), respectively.

REFERENCES

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U.S. Department of Energy. 1981. Nonresidential Buildings Energy Consumption Survey: Building Characteristics.

APPENDIX F

STRUCTURE AND USE OF DECON

INTRODUCTION

The computer program DECON is designed to provide a detailed analysis of site restoration requirements and activities for a radiologically contaminated area. The cleanup criteria are supplied by the user. Decontamination requirements are estimated from the cleanup criteria and from ground concentrations of radionuclides generated by CRAC2. Where the cleanup criteria are expressed in terms of dose or dose commitment, doses throughout the accident site are calculated using CRAC2 models and dose conversion factors.

This appendix provides a detailed description of the structure of DECON and contains instructions on its use.

PROGRAM STRUCTURE

DECON has a modular design and uses labeled common blocks for the majority of transfers. The primary logic structure is shown in Figure F.1. A hierarchy diagram of the main program and subroutines is shown in Figure F.2.

COMMON BLOCKS

DECON uses several named common blocks, the contents of which are described below.

Common Block PARMS

Symbol and Dimension	Type	Definition/Value/Units
IJM	Integer	Number of decontamination methods for all surfaces. The value is determined by the number of methods in the reference data base. IJM is currently 347. It has a maximum value of 350, but it can be increased by redimensioning several variables. A value for IJM is read from PARM.DAT (unit 10).
IJS	Integer	Number of decontamination operations for all surfaces. The value is determined by the number of operations in the reference data base. IJS is currently 186, with a maximum value of 200 without redimensioning of variables. A value for IJS is read from PARM.DAT (unit 10).
I20	Integer	Number of exposure (dose, dose commitment, or ground concentration) intervals. The value of I20 is user-specified, but it cannot be greater than 20 without redimensioning of variables. DECON determines in which of up to 20 exposure intervals each grid element falls. Using intervals rather than the actual exposure values can greatly reduce the computational time. A value for I20 is read from PARM.DAT (unit 10).
LNDUSE	Integer	Number of land use categories. The value of LNDUSE is currently 11, with a maximum value of 25. The land uses currently implemented are given in Table 3.1, page 3.4. A value for LNDUSE is read from PARM.DAT (unit 10).
NGE	Integer	Number of grid elements. The value of NGE is user-specified and has no maximum value. It is read from PARM.DAT (unit 10).

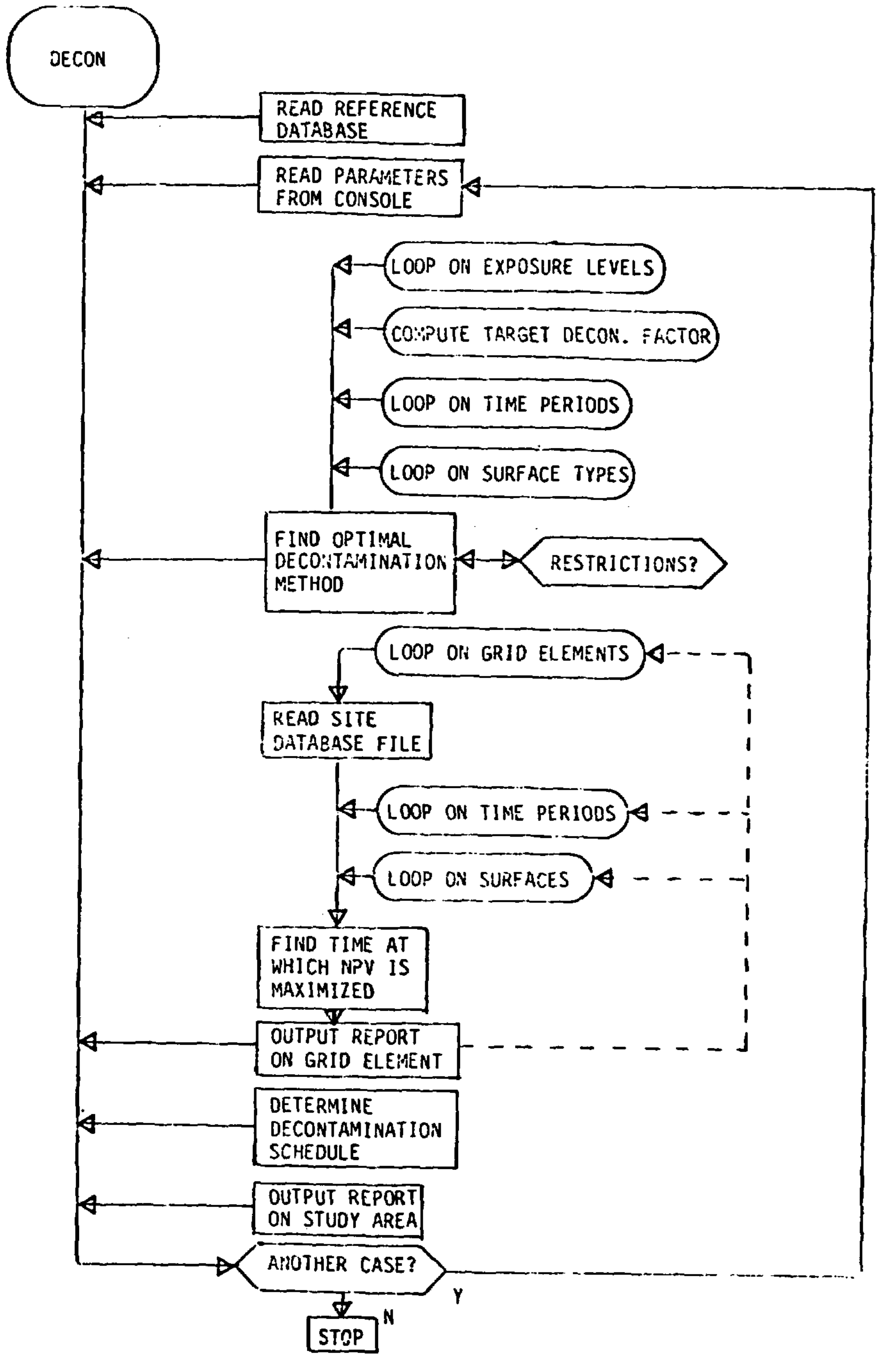

FIGURE F.1. Primary Logic of DECON

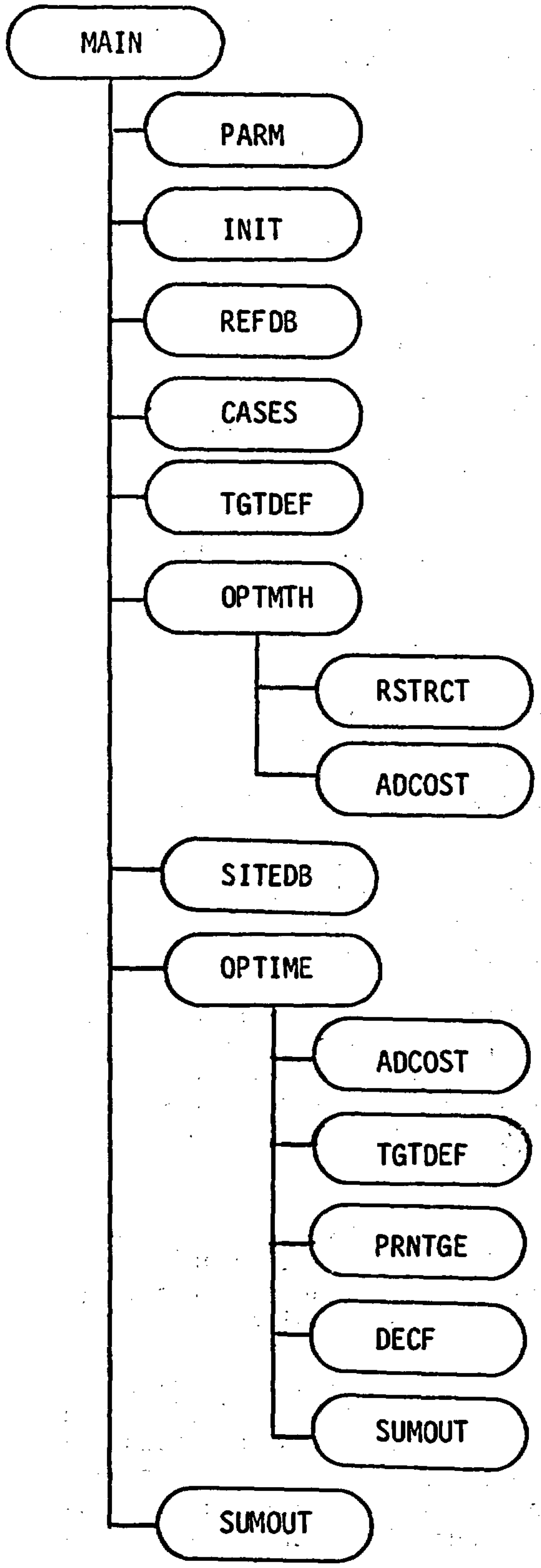

FIGURE F.2. Hierarchy of DECON

NPUTS	Integer	Number of factor inputs. The value of NPUTS is currently 90, with a maximum value of 125. It is read from PARM.DAT (unit 10).
NSURF	Integer	Number of surfaces. The value of NSURF is determined by the number of surfaces used in the reference data base. NSURF currently has a value of 24; its maximum value is 25. The surfaces currently implemented are given in Table 1.2, page 1.6. (Surfaces 17 and 22 are not currently used.) A value for NSURF is read from PARM.DAT (unit 10).
NTP	Integer	Number of time periods. It can have a value up to 30 (years) without redimensioning variables. It is user-specified and read from file PARM.DAT (unit 10).
P1	Real	Price adjustment factor for labor. All labor cost estimates are multiplied by this factor. P1 is read from file PARM.DAT (unit 10) and can also be changed by menu selection.
P2	Real	Price adjustment factor for equipment. All equipment cost estimates are multiplied by this factor. P2 is read from file PARM.DAT (unit 10) and can also be changed by menu selection.
P3	Real	Price adjustment factor for materials. All material cost estimates are multiplied by this factor. P3 is read from file PARM.DAT (unit 10) and can also be changed by menu selection.
P4	Real	Price adjustment factor for fuel. All fuel cost estimates are multiplied by this factor. Note, however, that separate fuel costs are not available for all decontamination methods. P4 is read from file PARM.DAT (unit 10) and can also be changed by menu selection.
RAINFL	Real	Average daily rainfall in inches. The value of RAINFL is user-specified. It has a default value of 0.1 and can be changed via menu selection. (It is not currently used in any calculations.)
RAINPR	Real	Average daily probability of rain. The value of RAINPR is user-specified. It has a default value of 0.32 and can be changed via menu selection. It is used in computing the probability of rainfall prior to the completion of decontamination activities. Rainfall will generally increase the difficulty and cost of decontamination.

RHO	Real	Discount rate. The value of rho is used in computing property losses due to loss of use of property while the property remains contaminated. It has a default value of 0.1 and can be changed via menu selection.

Common Block RFDAT

Symbol and Dimension	Type	Definition/Value/Units
CODEM(350)	Integer	Code value for each decontamination method. This variable is used for internal computations. The values for CODEM are read from file CODEX.DAT (unit 5).
COST(350)	Real	Cost of each decontamination method, measured in dollars per square meter. The information is contained in the reference data base on file MTHDAT.DAT (unit 8).
EFF(700)	Real	Decontamination efficiencies for inhalation pathway (1-350) and external exposure pathway (351-700). This variable is measured in units of percent. The information is contained in the reference data base on file MTHDAT.DAT (unit 8).
EXPOS(25)	Real	Exposure factor for each surface. The values for EXPOS are user-specified, with one value for each of the NSURF surfaces (see common block PARM). The default value for the elements of this array is 1.0; other values can be specified via menu selection. Exposure factors are discussed in Section 4.3.5, page 4.11. Their use is illustrated in Section 5.2.6, page 5.16.
FICODE(30)	Integer	Code value for factor input. Code values are for internal accounting purposes only. They are read from the reference data base file, MTHDAT.DAT, on unit 8. A maximum of 30 types of factor inputs can be specified for each decontamination method.
HAULS(350)	Real	Conversion factor for each decontamination method, relating the cubic meters of radiological waste produced for each square meter of surface area decontaminated. Values for this variable are read from the reference data base file, MTHDAT.DAT, on unit 8.

HDIST	Real	Average hauling distance from decontamination site to disposal site, measured in miles one-way. This variable is user-specified, with a default value of 30.0; it can be changed via menu selection. HDIST is used in computing the cost of hauling radioactive wastes resulting from decontamination.
IJM1	Integer	Variable that equals IJM+1. It is used for internal accounting and denotes that no decontamination is required.
IJM2	Integer	Variable that equals IJM+2. It is used for internal accounting and denotes that adequate decontamination cannot be accomplished with methods available in DECON.
ILABOR	Integer	The total number of factor input slots reserved for labor inputs. Used only for internal accounting purposes.
INPUTS(30)	Real	Contains the number of each type of factor input required for a specific decontamination method. Values for this variable are read from the reference data base file, MTHDAT.DAT, on unit 8. A maximum of 30 types of factor inputs can be specified for each decontamination method.
NMAX	Integer	Maximum number of decontamination methods available for any surface. NMAX is equal to the largest of the NUMSRF. It is used for internal accounting purposes only and is specified in PARM.DAT (unit 10).
NUMSRF(50)	Integer	Number of decontamination methods available for each surface. The sum of the NUMSRF must equal the value for IJM. Values for NUMSRF are read from PARM.DAT (unit 10).
RATE(350)	Real	Rate of each decontamination method, measured in square meters per hour. The information is contained in the reference data base on file MTHDAT.DAT (unit 8).
RCOSTK	Real	Ratio of equipment cost to total cost for current method. The information is contained in the reference data base on file MTHDAT.DAT (unit 8).
RCOSTL	Real	Ratio of labor cost to total cost for current method. The information is contained in the reference data base on file MTHDAT.DAT (unit 8).

TREES2	Real	The present value of orchard trees. This value is lost when decontamination requires removal and disposal of these trees. It is measured in dollars per square meter of orchard decontaminated. The default value is $2.06, and it can be changed via menu selection.
TREES4	Real	The net present value of trees in wooded areas. It equals the present value of the trees if permitted to mature, less the value if harvested in the current period. This net present value is lost when decontamination requires removal and disposal of these trees. It is measured in dollars per square meter of wooded area decontaminated. The default value is currently $4.12, and it can be changed via menu selection.
WCUBE	Real	The volume of radiological waste resulting from decontamination operations within any grid element.
XWCUBE	Real	The volume of radiological waste resulting from decontamination operations within the study area.

Common Block RFDATA

Symbol and Dimension	Type	Definition/Value/Units
NPTLBL(125)	Alpha	Label for factor input variables. 99 factor input variables are currently defined. The values for NPTLBL are read from file NPTLBL.DAT (unit 7).
SRFLBL(25)	Alpha	Label for surface types. There are currently 24 surface types, with types 17 and 22 not being used. The values for SRFLBL are read from file SRFLBL.DAT (unit 6).
METH(350)	Alpha	Mnemonic symbol for each decontamination method. The symbols are defined in Table 1.1, page 1.5. The values for METH are contained in the reference data base and are read from file MTHDAT.DAT (unit 8).

Common Block CONSTS

Symbol and Dimension	Type	Definition/Value/Units
RADMIN	Real	The lowest dose, dose commitment or ground concentration that requires surveying and monitoring activities to be conducted. RADMIN has a default of value of 0.1 and can be changed by menu selection.

WEE	Real	An arbitrarily small positive constant. Equals 0.01 and is used only for internal computations.

Common Block CONSTA

Symbol and Dimension	Type	Definition/Value/Units
ANS	Alpha	Variable containing the value 'Y' (yes) or 'N' (no). Used for internal processing only.
BLNK	Alpha	Constant containing a blank character. Used for internal processing only.
HD	Alpha	Variable containing the value 'Y' (yes) or "N' (no) to indicate whether DECON is loaded onto a hard disk system.
N	Alpha	Constant containing the value 'N' (no). Used in comparing answers received from terminal when operating in interactive mode.
NOMER	Alpha	Variable containing a phrase used in output reports. Value of variable depends on whether DECON is operating in fast mode or normal mode.
STAR	Alpha	Constant containing the value '*'. Used as a symbol in output reports.
Y	Alpha	Constant containing the value 'Y' (yes). Used in comparing answers received from terminal when operating in interactive mode.
V	Alpha	Constant containing the value 'V'. Used for internal processing only.
VV	Alpha	Constant containing the value 'v'. Used to denote that a decontamination method with double vacuuming is used.

Common Block SITDAT

Symbol and Dimension	Type	Definition/Value/Units
AREA	Real	Contains the area of the current grid element. Measured in square meters. The value of area can be 1) set at some constant value, 2) read from file AREA.DAT on unit 11, or 3) defined within a user-supplied subroutine. Selection is made via menu.

CSURF(2,350)	Real	Contains the surface area decontaminated using each method. (Method 349 denotes area requiring no decontamination, and method 350 denotes area that could not be decontaminated with methods in reference data base.) CSURF(2,*) contains above information but with the early vacuuming strategy in effect (see Section 4.3.2, page 4.16).
DCOST	Real	Contains the cost of decontaminating the current grid element during the current time period. It is measured in dollars per square meter and is used for internal processing.
DEPR(25)	Real	Depreciation factor (for the effects of deterioration and obsolescence) for each land use type. The values for DEPR are user-specified, with one value for each of the LNDUSE land use categories (see common block PARM). The values are read in from PARM.DAT (unit 10), but they can also be specified via menu selection. The default values are: .15, .15, .15, .10, .00, .10, .00, .00, .05, .00, and .20. Depreciation factors are discussed in Section 4.2.1.2, page 4.4.
DEPRX	Real	A weighted sum of the depreciation factors DEPR(*). The weights are WTS(I), the percentage of each grid element in the I-th land use. DEPRX is used only for internal accounting purposes.
DISC(25)	Real	Discount factor for each land use type. Not to be confused with RHO, the discount rate. The discount factors relate to the diminished property value due to residual contamination remaining after site restoration. The values for DISC are user-specified, with one value for each of the LNDUSE land use categories (see common block PARM). The default values are: .15, .10, .10, .00, .05, .05, .25, .25, .25, .10, and .10; other values can be specified via menu selection. Discount factors are discussed in Section 4.2.1.1, page 4.3.
DISCX	Real	A weighted sum of the discount factors DISC(*). The weights are WTS(I), the percentage of each grid element in the I-th land use. DISCX is used only for internal accounting purposes.
FINPUT(125)	Real	Used in accumulating the quantity of each factor input that is required to decontaminate the current grid element in the current time period.

GCE	Real	The exposure level (dose, dose commitment or ground concentration) for the current grid element. The value of GCE is contained in the site data base and is read from file SITEDB.DAT (unit 13).
GENPV	Real	Used to accumulate the net present value of all processed property within the current grid element.
IDAYS	Integer	The number of days before decontamination can be completed. This variable is user-specified, with a default value of 30. The value is specified via menu selection. IDAYS is used in calculating the probability of rain prior to the completion of decontamination activities. Rain affects decontamination efficiencies and costs.
MATIJK(2,30,25)	Integer	Each value of MATIJK contains the code number of the optimal method to use on a particular surface in a given time period, given the exposure level. The first subscript refers to decontamination prior to precipitation (MATIJK(1,*,*)) and after precipitation (MATIJK(2,*,*)); the second subscript refers to the time period (year following release); and the third subscript refers to the type of surface. This variable is used only for internal processing.
PBVAL	Real	The pre-accident value of property within the current grid element. Measured in dollars and taken as the market value at the time immediately preceding the radiological release. The value for PBVAL is contained in the site data base and is read from file SITEDB.DAT (unit 13).
PDVAL	Real	The post-decontamination value of property within the current grid element. For any particular land use, the post-decontamination value is equal to the pre-accident value multiplied by 1.0 minus the discount factor DISC. For the grid element, PDVAL is the sum of the post-decontamination values for the individual land uses. (See Section 4.2.1.1, page 4.3.) The value for PDVAL is contained in the site data base and is read from file SITEDB.DAT (unit 13).
POPS	REAL	The population in the current grid element. The value for POPS is contained in the site data base and is read from file SITEDB.DAT (unit 13).

RADLIM(8)	Real	The radiation limit, exposure limit or cleanup criteria with respect to any of up to 8 body organs. The values are user-specified and are read from PARM.DAT (unit 10). The values can also be changed via menu selection.
SCALE	Real	A scale value, usually some power of 10, to enable output values to be expressed in fixed decimal format. The value for scale is user-specified and is read in file PARM.DAT on unit 10.
SURF(25)	Real	The square meters of surface area for each surface type within the current grid element. The value for SURF is contained in the site data base and is read from file SITEDB.DAT (unit 13).
TPOPS	Real	The population in the study area. TPOPS is equal to the sum of the population, POPS, within each grid element located in the study area.
TOTSRF	Real	The total surface area within each grid element that requires decontamination. Measured in square meters of surface area.
TXTSRF	Real	The total surface area within each grid element that requires no decontamination. Measured in square meters of surface area.
XSURF(25)	Real	For the study area, the total square meters of each type of surface that could not be decontaminated using methods currently in the reference database.
WTS(25)	Real	Weights representing the percentage of the area within a grid element that is of each land use type. The weights are contained in the site data base and are read from file SITEDB.DAT (unit 13).

Common Block CASE

Symbol and Dimension	Type	Definition/Value/Units
AREAF	Real	Switch to determine whether the area of each grid element is to be 1) set to some constant value, 2) read from file AREA.DAT on unit 11, or 3) defined within a user-supplied subroutine. Default is for AREA to be set to constant value of 10,000 square meters. Selection is made via menu.

CDOSE	Real	External dose commitment to the resident population of the current grid element. Commitment period begins at time of resettlement following decontamination.
DD(20,25)	Real	Contains the total area contaminated, by exposure are and by surface type. The first subscript refers to exposure area and the second subscript to surface type. Used in the single-period, fast mode of analysis.
IACT	Integer	Switch to denote whether DECON is to be run in interactive or batch mode. (Batch mode is not currently implemented.)
IADD	Integer	Parameter to indicate what special constraints are in effect (e.g., Quick-Vac, operation restrictions, required methods, etc.). Used only for internal processing.
IDRSV	Integer	Switch to indicate whether console message is to be written requesting user to change disks in a particular drive. Used when large site database requires multiple diskettes. Used only for internal processing.
ING	Integer	Counter used in keeping track of number of paired values used to define subarea boundaries in subarea analysis. (See Section 4.3.1, page 4.9.) Used only for internal processing.
IPDQ	Integer	Switch used to indicate whether Quick-Vac option is selected (IPDQ=1) or deselected (IPDQ=0). Default value is zero. Option is made via menu selection.
IPRCST	Integer	Print status parameter to indicate what reports are to be produced. Options are: 1 - As 2 - As + Af 3 - As + Af + Aa 4 - As + Gs 5 - As + Gs + Gf 6 - As + Gs + Gf + Ga 7 - As + Gs + Gf + Ga + Gd 8 - As + Xs 9 - As + Xs + Xf 10 - As + Xs + Xf + Xa 11 - As + Xs + Xf + Xa + Xd

		where A = Study area G = Grid element X = Exposure area and s = Summary results f = Factor inputs a = Area decontaminated, by surface and method d = detailed surface analysis. For example, setting IPRCST equal to 5 produces 1) summary results for the study area, 2) summary results for each grid element, and 3) factor input requirements by grid element. Exposure area results are available only in fast mode, and grid element results are available only in normal mode. A value for IPRCST is requested by DECON when it begins processing. The value can also be changed by menu selection.
IPRNT(25)	Integer	Contains numbers of up to 25 grid elements for which detailed analysis is to be provided (equivalent to IPRCST=7, or IPRCST=11). Normally used when there are a large number of grid elements to be processed and detailed results are wanted on only a few of them. Option selected by menu.
IQV	Integer	Switch used in connection with Quick-Vac option. Used for internal proocessing only.
IQWIK	Integer	Switch used to indicate fast mode of processing. Internally set when number of periods to be analyzed is 1 and IPRCST has a value less than 4 or greater than 7.
IRSTF(100)	Integer	One of 4 parameter values set in connection with operation restrictions and/or required methods. IRSTF is the number of the last exposure area to which the restriction/requirement applies. Up to 100 restrictions and/or requirements can be imposed in a single case. (See Sections 4.3.3 and 4.3.4, page 4.10) Note that if restrictions or requirements are to apply to a subarea within the study area, they must be applied to exposure areas rather than grid elements. This option is activated via menu selection.
IRSTS(100)	Integer	One of 4 parameter values set in connection with operation restrictions and/or required methods. IRSTS is the number of the first exposure area to which the restriction/requirement applies. Up to 100 restrictions and/or requirements can be imposed in a single case. (See Sections 4.3.3 and

		4.3.4, page 4.10.) Note that if restrictions or requirements are to apply to a subarea within the study area, they must be applied to exposure areas rather than grid elements. This option is activated via menu selection.
ISRF(100)	Integer	One of 4 parameter values set in connection with operation restrictions and/or required methods. ISRF defines the surface or surfaces to which the restriction/requirement applies. A value of 99 results in the restriction/requirement applying to all surfaces; otherwise, only a single surface is affected. A positive value indicates a restriction, while a negative value indicates a requirement. Up to 100 restrictions and/or requirements can be imposed in a single case. (See Sections 4.3.3 and 4.3.4, page 4.10.) Note that if restrictions or requirements are to apply to a subarea within the study area, they must be applied to exposure areas, rather than grid elements. This option is activated via menu selection.
ISTART	Integer	Switch used to indicate whether the first case is being processed, or subsequent cases. Used for internal processing only.
NGF(50)	Integer	One of two parameters used to define the boundaries of a subarea to be analyzed. NGF is the last grid element in the "row" of grid elements to be processed. Up to 50 "rows" of grid elements can be included within the subarea. (See Section 4.3.1, page 4.9.) This option is specified by menu selection.
NGS(50)	Integer	One of two parameters used to define the boundaries of a subarea to be analyzed. NGS is the first grid element in the "row" of grid elements to be processed. Up to 50 "rows" of grid elements can be included within the subarea. (See Section 4.3.1, page 4.9.) This option is specified by menu selection.
NGSS	Integer	The first grid element in the study area to be processed. NGSS is set equal to NGS(1) unless IPRCST is greater than 7, in which case NGSS=1. Used only for internal processing.
NNFF	Integer	The final grid element in the study area to be processed. NNFF is set equal to the last nonzero value of NGF if grid elements are being processed; NNFF is set equal to I20 if exposure areas are being processed. If NGF(1) is zero NNFF is set equal to the number of grid elements in the study area. Used only for internal processing.

NORG	Integer	The number of body organs to be processed in determining target decontamination factor (see Section 4.2.2, page 4.5, and footnote 4 on page 4.7). In the current implementation of DECON, NORG must equal 1. The value for NORG is user-specified. It is read from file PARM.DAT on unit 10.
PSAV1	Real	Contains the potential savings from a property buy-out, where the buy-out is made at pre-accident property values. PSAV1 will have a nonzero value in circumstances where the cost of decontamination exceeds the pre-accident value of the property. PSAV1 provides information that may be useful in determining the cost of providing compensation. The value for PSAV1 is internally generated.
PSAV2	Real	Contains the potential savings from a property buy-out, where the buy-out is made at the net present value of the property immediately after the accident. PSAV2 will have a nonzero value in circumstances where the cost of decontamination exceeds the social value of the property. PSAV2 provides information that may be useful in minimizing the social cost of the accident. The value for PSAV2 is internally generated.
SAVSRF(25)	Integer	Used internally to optimize processing efficiency.
SMCOST	Real	Total surveying and monitoring costs in each grid element.
TFNPUT(125)	Real	Used in accumulating the quantity of each factor input that is required to decontaminate the entire study area.
TPBVAL	Real	The pre-accident value of property within the study area. Measured in dollars and taken as the market value at the time immediately preceding the radiological release. The value for TPBVAL is the sum of PBVAL for each grid element in the study area.
TPDVAL	Real	The post-decontamination value of property within the study area. The value for TPDVAL is the sum of PDVAL for each grid element in the study area.
TSMCST	Real	Total surveying and monitoring costs within the study area.

TTCOST	Real	Contains the cost of decontaminating the study area. It is measured in dollars per square meter and is the sum of DCOST for each grid element in the study area.
TTTSRF	Real	The total surface area within the study area that requires decontamination. It is measured in square meters of surface area. TTTSRF is the sum of TOTSRF for each grid element in the study area.
WDOSE	Real	External dose commitment to decontamination workers within the current grid element. It is measured in man-rem. Commitment period begins in year of decontamination.
XGCE(20)	Real	Contains the upper bound of each exposure (dose, dose commitment, or ground concentration) interval. The values for XGCE are user-specified; a maximum of 20 are allowed without redimensioning of variables. DECON determines in which exposure interval each grid element falls. Using intervals rather than the actual exposure values can greatly reduce the computational time. The values for XGCE are read from file PARM.DAT (unit 10).
XIT	Integer	Switch to indicate when processing is completed. Program is terminated when XIT equals 1.
XNODEC	Real	Contains the total surface area within the study area that requires no decontamination. It is measured in square meters of surface area. XNODEC is the sum of XXNDEC for each grid element in the study area.
XPBVAL(20)	Real	The pre-accident value of property within each exposure area. Used only in the fast mode of operation. Measured in dollars and taken as the market value at the time immediately preceding the radiological release. The value for XPBVAL(I) is the sum of PBVAL for each grid element with an exposure level in the I-th exposure interval.
XPDVAL(20)	Real	The post-decontamination value of property within each exposure area. Used only in the fast mode of operation. The value for XPDVAL(I) is the sum of PDVAL for each grid element with an exposure level in the I-th exposure interval.
XTPOPS(20)	Real	The total population within each exposure area. Used only in the fast mode of operation. The value for XTPOPS(I) is the sum of POPS for each grid element with an exposure level in the I-th exposure interval.

XXNDEC	Real	Contains the total surface area within each grid element that requires no decontamination. It is measured in square meters of surface area.
XXXSRF	Real	For the study area, the total surface area that could not be decontaminated using methods currently in the reference database.
XCDOSE	Real	For the study area, the external dose commitment to the resident population. The commitment period begins at time of resettlement of the decontaminated areas.
XWDOSE	Real	For the study area, the external dose commitment to decontamination workers. XWDOSE is measured in man-rem. Commitment period begins in year of decontamination.

Common Block CASEA

Symbol and Dimension	Type	Definition/Value/Units
SRSTA(100)	Alpha	One of 4 parameter values set in connection with operation restrictions and/or required methods. SRSTA is alphanumeric code for the operation or method that is being restricted. Up to 100 restrictions and/or requirements can be imposed in a single case. (See Sections 4.3.3 and 4.3.4, page 4.10) Note that if restrictions or requirements are to apply to a subarea within the study area, they must be applied to exposure areas rather than grid elements. This option is activated via menu selection.

Common Block DOSE

Symbol and Dimension	Type	Definition/Value/Units
DECAY(30)	Real	Factors used in calculating the exposure levels in the current time period. These factors adjust for radioactive decay and weathering and give the proportion of exposure remaining relative to the exposure level in the first period. A maximum of 30 time periods can be used without redimensioning of variables. The values for DECAY are read from file DOSERATE.DAT on unit 12. This file is created by the dose model (see Appendix E, p. E.1).

DKR(30)	Real	A maximum of 30 time periods can be used without redimensioning of variables. The values for DKR are read from file DOSERATE.DAT on unit 12. This file is created by the dose model (see Appendix E, p. E.1).
DRATIO	Real	The dose rate at time zero. Measured in rem per hour. The values for DRATIO are read from file DOSERATE.DAT on unit 12. This file is created by the dose model (see Appendix E, p. E.1).
R2	Real	The 7-year dose commitment taken 14 days after release. Measured in rem. The values for DRATIO are read from file DOSERATE.DAT on unit 12. This file is created by the dose model (see Appendix E, p. E.1).
SHELD1	Real	Shielding factor used for decontamination workers. SHELD1 gives the fraction of the total dose received by the decontamination worker. The roughness of the contaminated surface is assumed to give a shielding factor of 0.5 (see USNRC 1975). The use of protective clothing may reduce the shielding factor even further. The value for SHELD1 can be modified via menu selection.
SHELD2	Real	Shielding factor used for resident population. SHELD2 gives the fraction of the total dose received by a typical resident of the affected area. The roughness of the contaminated surface is assumed to give a shielding factor of 0.5 (see USNRC 1975). SHELD2 will be further reduced by protective measures (other than decontamination) and/or the shielding effect of materials. The value for SHELD1 can be modified via menu selection.

Common Block HLTH

Symbol and Dimension	Type	Definition/Value/Units
NORGUS	Integer	The number of organs considered in establishing the decontamination criteria. The value of NORGUS is constrained to 1 in the current implementation of DECON.

DATA FILES

Entry of data into DECON is by console in the interactive mode and from several input files. The input files are:

```
Unit 5 - CODEX    .DAT - codes for decontamination methods
Unit 6 - SRFLBL   .DAT - labels for surface types
Unit 7 - NPTLBL   .DAT - labels for factor inputs
Unit 8 - MTHDAT   .DAT - data from the reference database
Unit 10- PARM     .DAT - parameter values
Unit 11- AREA     .DAT - areas for each grid element
Unit 12- DOSERATE.DAT - data relating to exposure levels
Unit 13- SITEDB   .DAT - site database
Unit 14- SITEDB2  .DAT - extended site database
```

Unit 11 is read only if the user selects to read the area of each grid element from an input file. Unit 14 is read only if the size of the site database is too large to be contained on a single diskette. For a single-sided drive, one diskette will hold the data for 750 grid elements. If unit 14 is required, DECON will prompt the user to mount the second diskette.

A description of each input file and the format in which the data must be prepared is described below. The user of DECON must only prepare the file PARM.DAT; the other files are either pre-prepared as part of the reference database, or they are prepared in other programs requiring user input. These other programs are described in Appendix D. Information supplied to DECON via menu selection is described in a later section.

Codes for Decontamination Methods; CODEX.DAT - Unit 5

This file is prepared by the program REFDATA, which prepares the reference database (see Appendix D). CODEX.DAT must be on the default drive.

Labels for Surface Types; SRFLBL.DAT - Unit 6

This file is modified only when changing the number or types of surfaces supported by the reference database. See Appendix D. SRFLBL.DAT must be on the default drive.

Labels for Factor Inputs; NPTLBL.DAT - Unit 7

This file is modified only when changing the number or types of factor inputs supported by the reference database. See Appendix D. NPTLBL.DAT must be on the default drive.

Data from the Reference Database; MTHDAT.DAT - Unit 8

This file is prepared by the program REFDATA. It is modified only when adding data to or changing data in the reference database. See Appendix D. MTHDAT.DAT must be on the default drive.

Parameter Values; PARM.DAT - Unit 10

This file is prepared by the user and must reside on the default drive. The variables read and the format in which the variables must appear is described below.

The following 11 variables are read in Fortran format (9I8).

NGE - number of grid elements in the site database

NSURF - number of surface types in the reference database; current value is 24 (numbers 17 and 22 are not currently used).

NMAX - maximum number of decontamination methods available for any surface. The current value is 30.

LNDUSE - the number of land use categories. The current value is 11, and the categories are as follows: 1) residential, 2) commercial, 3) industrial, 4) streets and roads, 5) wooded areas, 6) parking lots, 7) grain crops, 8) vegetable crops, 9) orchards, 10) vacant land and 11) automobiles.

NPUTS - the number of factor inputs. The current value is 90.

NORGUS - the number of body organs to be processed. The maximum value for NORGUS is currently constrained to the value 1.

IJM - the number of decontamination methods in the reference database. The current value is 347.

IJS - the number of decontamination operations in the reference database. The current value is 186.

NTP - the number of time periods to be considered. Any value from 1 to 30, inclusive.

I20 - the number of exposure intervals to be used. Any value from 1 to 20, inclusive.

IACT - Set to 0 if batch processing mode is used; set to 1 if interactive mode at console is used. (Current implementation is only for IACT=1.)

The variable (NUMSRF(I),I=1,NSURF) is read in format (9I8). NUMSRF contains the number of decontamination methods available for each surface. The current values for NUMSRF are: 30, 20, 25, 13, 19, 23, 13, 16, 11, 17, 13, 17, 23, 23, 11, 11, 0, 5, 6, 4, 5, 0, 21, 21.

The variable (RADLIM(I),I=1,NORGUS) is read in format (9F8.2,F7.2). RADLIM contains the radiation limit, exposure limit, or cleanup criterion with respect to NORGUS body organs. RADLIM must be in the same units of measurement as GCE, which is read from the site database. The units of GCE are user-selectable. (The current implementation of DECON requires that NORGUS equals 1.)

The variable (XGCE(I),I=1,I20) is read in format (9F8.2,F7.2). XGCE contains the midpoint of each exposure (dose, dose commitment, or ground concentration) interval. The value of GCE is read for each grid element in the site database, and it is then determined in which of the XGCE exposure intervals GCE falls. The grid element is then processed as though GCE were equal to the value of XGCE for the interval in which it falls. For example, if XGCE(1)=2.5, XGCE(2)=10.0 and GCE=8.1, then GCE will fall in exposure interval 2 and the grid element will be processed as though GCE had equaled 10.0. It is assumed that the lower bound of the first interval is equal to 0.0. All values of GCE greater than the midpoint of the last interval will assume the value of the final XGCE specified.

The variable (DEPR(I),I=1,LNDUSE) is read in format (9F8.2,F7.2). DEPR contains the depreciation rates to be associated with each land use category. This is depreciation due to deterioration and obsolescence of property. The values for the DEPR are expressed as the fraction of the property value lost from one year to the following year. For example, DEPR(3)=0.1 means that property in land use category 3 (industrial) loses 10 percent of its value every year due to deterioration and obsolescence.

The variable (DISC(I),I=1,LNDUSE) is read in format (9F8.2,F7.2). DISC contains the fraction of a property's pre-accident value that is lost because of residual contamination remaining after it has been decontaminated. For example, DISC(9)=0.2 means that property in land use category 9 (orchards) would lose 20 percent of its pre-accident value simply as a result of residual contamination.

The next set of variables read from PARM.DAT is P1, P2, P3, P4 and SCALE. The format is (9F8.2,F7.2). P1 through P4 are factors that can be used to adjust the costs of labor (P1), equipment (P2), materials (P3) and fuel (P4). These costs are actually adjusted in the program REFDATA, which also uses the file PARM.DAT.

For severe accidents, the costs, areas and hours of labor and equipment are large numbers and need to be scaled down if they are to be expressed in fixed decimal format. The variable SCALE permits the user to scale the output results. SCALE is usually expressed as some power of 10, and is entered in PARM.DAT in scientific notation. For example, the value 1.0E+03 would cause values expressed in dollars, areas, and hours of labor and equipment to be scaled down by a factor of 1000.

The last variable, (EXPOS(I),I=1,NSURF), is read in format (9F8.2,F7.2). EXPOS contains the exposure factors to be associated with each type of surface. Exposure factors are discussed in Section 4.3.5, page 4.11 and illustrated in Section 5.2.6, page 5.16. It is recommended that the values for EXPOS be set to 1.0 for base case evaluations.

<u>Areas of Grid Elements; AREA.DAT - Unit 11</u>

This file is required only if the user specifies that grid element areas are to be read from a file. AREA.DAT must be on the default drive.

Data Relating to Doses; DOSERATE.DAT - Unit 12

This file contains information relating to doses and dose commitments. It contains 1) the dose rate at time zero in rem per hour; 2) the 70-year dose commitment, taken 14 days after release, measured in rem; 3) the relative decay factors of the 70-year dose commitments; and 4) the relative decay factors of the dose rates. This file is prepared by the dose model and is modified only when a different source term is used. See Appendix E.

Data Relating to the Site Database; SITEDB.DAT - Unit 13

This file, which is prepared by the program SITEDATA, contains all of the information relating to the site database. One random access record is provided for each grid element. Each record contains 1) the record number; 2) the pre-accident value of the property within the grid element; 3) the post-decontamination value of the property (as computed from the variable, DISC); 4) the exposure level (dose, dose commitment or ground concentration); 5) the population; 6) the area of the grid element; 7) the percentage of the grid element in each of land uses one through four; 8) the percentage of the grid element in each of land uses five through eight; 9) the percentage of the grid element in each of land uses nine through 12; and 10) for each surface type, the ratio of the area for that surface type to the total geographic area of the grid element. If DECON is on a hard disk, SITEDB.DAT should be on the default drive. If DECON is run on floppy disks, the default drive is drive A: and SITEDB.DAT is read from drive B:.

Extended Site Database; SITEDB2.DAT - Unit 14

This file is simply an extension of SITEDB.DAT. It is used only when the number of grid elements exceeds 750.

USER'S GUIDE

This section is a user's guide to DECON. It assumes that all of the input files described above are properly prepared and mounted.

Three diskettes are required to run DECON. Diskette No. 1 contains:

DECON.EXE -- The program "DECON"

Diskette No. 2 contains:

NPTLBL.DAT -- An ASCII file containing labels for the factor inputs
SRFLBL.DAT -- An ASCII file containing labels for the surface types
MTHDAT.DAT -- A random access file containing the reference data set
CODEX.DAT -- An ASCII file containing decontamination method codes
PARM.DAT -- An ASCII file containing parameter values for DECON
DOSERATE.DAT- An ASCII file containing dose decay factors
AREA.DAT -- A random access file containing the area of each grid element

Diskette No. 3 contains the site database; namely:

SITEDB.DAT -- A random access file containing a record of information for the first 750 grid elements of the accident site.

Diskette No. 4 (if needed) contains:

SITEDB2.DAT-- A random access file containing a record of information for grid elements 751 thru 1550 of the accident site.

To run DECON, make Drive A: the default drive and place Diskette No. 2 in this drive. Place Diskette No. 1 in Drive B: and at the console enter B:DECON. DECON will respond with "ENTER OUTPUT CONTROL VARIABLE." The user responds with an integer number, which will control the amount of output, as follows:

Control Integer	Output Produced	Output Codes
1	As	A = Study area
2	As + Af	G = Grid element
3	As + Af + Aa	X = Exposure area
4	As + Gs	s = Summary results
5	As + Gs + Gf	f = Factor inputs
6	As + Gs + Gf + Ga	a = Area decontaminated, by surface and method
7	As + Gs + Gf + Ga + Gd	d = Detailed surface analysis
8	As + Xs	
9	As + Xs + Xf	
10	As + Xs + Xf + Xa	
11	As + Xs + Xf + Xa + Xd	

For example, a control integer of 5 produces 1) summary results for the study area, 2) summary results for each grid element, and 3) factor input requirements by grid element. Exposure area results are available only in fast mode, and grid element results are available only in normal mode. The value of the control integer can also be changed by menu selection.

DECON will operate in FAST mode if a single time period is to be analyzed and the control integer is either less than 4 or greater than 7. The saving in processing time when operating in FAST mode will be particularly significant if a large number of grid elements is to be processed.

The next request by DECON will be a message to "ENTER LINE PRINTER STATUS." If a '0' (zero) is entered, all output will be at the console; if a '1' (one) is entered, reports will be produced at the line printer (device LPT1:).

DECON next asks if a previously generated matrix is to be used. This matrix is contained in file MATIJK.DAT, which must be in Diskette No. 2. It is created by DECON and contains, for each exposure interval, the optimal decontamination method to be used on each surface and at each time period. Using a previously generated matrix will usually shorten processing time by several minutes. However, if any of the following are changed, a new matrix must be generated:

Description	Name of Variable	File Location
Number of exposure intevals	I20	PARM.DAT
Value of exposure interval limits	XGCE(*)	PARM.DAT
Radiation limit/cleanup standard	RADLIM(*)	PARM.DAT/Menu
Restricted operations and/or required methods	ISRF(*)	Menu
Exposure factors	EXPOS(*)	PARM.DAT/Menu
Radioactive decay factors	DECAY(*)	DOSE.DAT
Factor input cost adjustment factors	P1,P2,P3,P4	PARM.DAT
Costs/Efficiencies of Methods	COST(*)/EFF(*)	METHDAT.DAT

If a previously generated matrix is used, DECON will ask, "DO YOU WISH TO SAVE THE PARAMETER VALUES FROM THE PREVIOUS CASE? (Y/N)." If you answer yes, previous parameter values are saved. However, you will still be permitted to make changes via the menu. If you answer no, then subarea boundary definitions, restrictions on operations, required methods, the Quick-Vac option and detailed printout for selected grid elements will all be deactivated.

The next processing step is to read the reference data base. After doing this, DECON will display the DATA ENTRY MENU, followed by the message "ENTER TASK CODE 1 TO 20, OR -1 TO STOP." The user responds by entering one or more integer numbers. Depending upon the number entered, various options can be selected. They are described as follows:

Number	Factor	Option Description
1	RAIN PROBABILITY	Enter a value for the daily probability of rain (a value between 0.0 and 1.0). Default value is 0.32.
2	RAINFALL	Enter a value for the average daily rainfall (a value between 0.0 and 99999.0). Default value is 0.1.
3	STUDY AREA BOUNDARIES	Enter a pair of values to delimit the set of grid elements to be analyzed. The first value is the number of the starting grid element, and the second value is the number of the ending grid element. A subarea of the study area may be analyzed by using several sets of delimiters to define the boundaries of the subarea. Up to 50 pairs of delimiters can be used.
4	QUICK-VAC	Enter a value of 1 to activate the Quick-Vac option. Default value is 0. (Not currently implemented.)
5	DAYS TO COMPLETE DECONTAMINATION	Enter an integer value for the number of days before decontamination is completed. This value is used to calculate the probability of rain prior to the completion of decontamination.
6	SCALE	Enter a scale factor, normally some power of 10, to enable output values to be expressed in fixed decimal format. The value for scale affects all units measured in dollars, area and man- and equipment-hours. For example, a scale factor of 1.0E+03 will cause all variables measured in dollars, area and man- and equipment-hours to be scaled down by a factor of 1000.
7	DISCOUNT RATE	Enter a value for the discount rate. Default value is 0.1 (= 10%).
8	RADIATION LIMIT	Enter values for: 1) the organ number (enter 1 only), 2) the dose commitment period (enter 1 only), and 3) the radiation limit for total dose.
9	RESTRICTIONS ON OPERATIONS OR METHODS	Enter values for: 1) the starting exposure area, 2) the ending exposure area, 3) the surface number being restricted (see Table 1.2), and 4) the operation or method being restricted (see Table 1.1). A positive value for the surface number denotes that all methods containing the indicated operation are to be excluded. A negative value for the surface number denotes that only the method specified is to be used. To designate all surfaces, enter a 99 for the surface number. The operation/method that is being restricted must be entered within single quote marks.

		Examples: 1,20,3,'W' - for exposure areas 1 through 20 do not use methods containing water on surface 3 (vacant land); 15,15,-15,'CR' - for the fifteenth exposure area, decontaminate roofs using a strippable coating followed by removal and replacement.
10	OUTPUT OPTIONS	Select from the following: 1) change output control variable, 2) change line printer status, or 3) change grid elements that are selected for microanalysis. If 1) is selected, enter a value for the output control variable; see options above. If 2) is selected enter a value for the line printer status; see options above. If option 3) is selected and if the output control variable is less than 7, enter grid element numbers to obtain detailed analyses of those grid elements. If output control variable is between 8 and 10, enter exposure area numbers to obtain detailed analyses of those exposure areas. Up to 50 grid elements/exposure areas may be specified. NOTE: Use of this option automatically overrides the FAST mode of DECON.
11	GRID ELEMENT AREA	Enter a value for the size of the grid element in square meters; or designate that areas are to be read from AREA.DAT; or designate that areas are to be obtained from a user-supplied subroutine. Default value for grid element area is 10000 sq. meters.
12	PROPERTY LOSS FACTORS	Enter a set of values (= to the number of land uses) to indicate the fraction of original property value lost due to residual contamination remaining after decontamination has been completed. Default value = 0.1 (= 10%).
13	EXPOSURE FACTORS	Enter a set of values (= to the number of surface types) to denote relative human exposure to surface type. Default value = 1.0.
14	CHANGE #3, #9 OR #10	Change existing values for selected 1) grid element delimiters, 2) restrictions, or 3) grid elements selected for microanalysis. Change values from those used in previous case, or deactivate by initializing equal to zero.
15	NUMBER OF TIME PERIODS	Enter a value from 1 to 30 to indicate the number of time periods to be considered in the analysis. Increasing the number of time periods increases the period used in determining the decontamination schedule.

16	COST ADJUSTMENTS	Submenu: Enter factors by which to increase or decrease a) labor costs, b) equipment costs, c) costs of materials, and d) fuels costs. Enter a value (in dollars per square meter) for the net present value lost from the income stream caused by premature removal of a) orchard trees or b) forest trees.
17	HAULING DISTANCE	Enter a value for the average one-way hauling distance between cleanup site and disposal site; default is 30 miles.
18	SHIELDING FACTORS	Enter a value for the average shielding effect to a) radiation workers; b) resettled population. The default values are 0.5 for both.

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This report documents a data base and a computer program for conducting a decontamination analysis of a large, radiologically contaminated area. The data base, which was compiled largely through interviews with knowledgeable persons both in the public and private sectors, consists of the costs, physical inputs, rates and contaminant removal efficiencies of a large number of decontamination procedures. The computer program utilizes this data base along with information specific to the contaminated site to provide detailed information that includes the least costly method for effectively decontaminating each surface at the site, various types of property losses associated with the contamination, the time at which each subarea within the site should be decontaminated to minimize these property losses, the quantity of various types of labor and equipment necessary to complete the decontamination, dose to radiation workers, the costs for surveying and monitoring activities, and the disposal costs associated with radiological waste generated during cleanup. The program and data base are demonstrated with a decontamination analysis of a hypothetical site.

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