APPENDIX TABLES (Cont.)

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# 1.0 INTRODUCTION

This study was conducted by the Pacific Northwest Laboratory (PNL) for the United States Nuclear Regulatory Commission (NRC), Division of Safety Review and Oversight, Office of Nuclear Reactor Regulation (NRR). It was undertaken to provide the NRC with improved technical information and enhanced analytical capabilities regarding accident consequences and 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 and producing quantitative results relevant to restoration of the site.

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 that analyzes the information is called *DECON*.

Chapter 2 describes the Reference Database. The chapter begins with a description of the contents of this database, which contains 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, the information in the Site Database is site-specific.

This means that the contents of the database for one site will generally be inappropriate for other sites. Rather than focusing on the actual values in the Site Database, we concentrate our efforts on evaluating alternative 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. The logical flow of DECON is described, as well as its various features and capabilities. Supporting software programs that have been developed for maintaining and updating the Reference Database and for preparing the Site Database are also discussed in this chapter.

The final chapter demonstrates the use of these three analytical resources by applying them to a case study consisting of a series of hypothetical reactor accidents. The reactor site selected for this analysis is Indian Point, which lies about 40 km to the north of New York City. Because the population density around this site is significantly higher than at most other reactor sites, the accident consequences are likely to be more severe than similar accidents at other reactor sites. In addition, the plume direction was selected in all cases to maximize the property-related losses; hence, the case study does not provide representative results.

This report also contains several appendices. The first two appendices provide detailed documentation for the Reference Database. Appendix A describes how the 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 two appendices was developed from information supplied by original sources. To facilitate updating of the Reference Database, these sources with their telephone numbers are supplied in Appendix C. It should be mentioned that the information on decontamination efficiencies in Appendix B has not been reevaluated since publication of the 1985 report. Meanwhile, new evidence on decontamination efficiencies has been and is currently being developed, based on actual field experiments. We anticipate that we will have an opportunity in the near future to reevaluate the decontamination efficiencies, but constraints on time and resources have prevented such a study at this time.

Appendix D documents the sources of the data and other information used in the Indian Point case study. Appendix E pertains to the Site Database. It describes the methods for characterizing an accident site, and it presents the technical relationships that are used to transform land use information into information on surfaces.

## 1.2 BACKGROUND

The current study builds on the research contained in the 1985 report (*Off-Site Consequences of Radiological Accidents: Methods, Costs, and Schedules for Decontamination*, (NUREG/CR-3413). This report was motivated by the NRC's need for more reliable information on the socioeconomic consequences of accidents at nuclear power plants. Accident consequence information is used in estimating the social costs of reducing health risks posed by the possibility of major accidents at nuclear power plants. Major policy areas in which reactor accident risks have been evaluated include the development and implementation of reactor safety goals and the assessment of alternative sites for yet-to-be-constructed nuclear facilities. To the extent such policy decisions 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), which must contain an assessment of the potential impacts of radiological accidents.

A severe radiological accident has the potential of causing early injuries and deaths, long-term cancers, genetic effects, and widespread damage to property. The off-site property losses from such an accident could run into the billions of dollars. To estimate these losses, the NRC relied 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.

Estimates of accident consequences from CRAC2 indicated that for severe accidents the land interdiction and decontamination costs tend to dominate the other estimated accident costs. It was therefore reasonable that these costs should be reconsidered in any attempt to improve on this information. In addition to reexamining these costs, the 1985 report also evaluated other components of social costs not addressed by CRAC2.

Since publication of the 1985 report, the Office of Radiation Programs in the U.S. Environmental Protection Agency (EPA) has also provided financial support to PNL's research in this area. EPA's interest stems from its responsibilities to develop reentry and relocation criteria for areas that might become contaminated from a severe reactor accident. In the event of such an accident, state and local officials would have to determine long-term relocation criteria. Long-term relocation criteria establish the conditions under which residents and businesses would be permitted to return to the affected areas on an unrestricted and permanent basis. In order to provide these officials with useful guidance, the EPA contracted with PNL to develop procedures

that could be applied by state and local agencies. These procedures, which can be implemented by making use of the resources described in this report, will enable the state and/or local agencies to develop for themselves the cleanup cost components and estimates of the health risks. PNL has also provided guidance for organizing these elements into a cost/risk framework. This format should make the results more useful to state and local decisionmakers as they select the relocation criteria.

Another agency that has provided financial support in this area is the U.S. Defense Nuclear Agency (DNA). The interest of this agency is in producing a management tool that can be used to evaluate the property-related costs and to develop and evaluate alternative site restoration strategies for areas contaminated as the result of a nuclear weapon accident. Following a weapon accident, U.S. Government officials would have two responsibilities to state and local officials: 1) to negotiate appropriate cleanup criteria, and 2) to develop a strategy for restoring the contaminated site to the agreed upon criteria. The resources described in this report have been used in field exercises that address both of these responsibilities.

## 1.3 OBJECTIVES

The 1985 report had as its major goal to build upon the methods used by the NRC to estimate the decontamination and interdiction costs of a severe radiological accident. Four major objectives were identified toward meeting this goal. The first objective was 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 involved conducting a literature search and interviewing individuals having experience or expertise in these areas.

The second objective was 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 third objective was to develop a methodology that would enable data commonly available by political subdivision to be mapped by software into the elements of the accident 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 in doing this can often become a major disincentive for conducting an analysis using site-specific information.

The last major objective was 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 site restoration activities at the accident site. This information was to include the effects of the accident on property values. The computer program was to be designed to significantly exceed the capabilities of CRAC2 in providing an accurate and informative analysis of site restoration activities and property value effects.

The primary objective of this revision to the 1985 report is to provide documentation of the capabilities that have been added to the software programs since publication of the 1985 report. These enhancements include:

Additions

- Eight additional contaminated surface categories: Exterior glass, exterior concrete walls, interior glass, reservoirs, soft-surface furnishings, hard-surface furnishings, electronic equipment, and paper products
- Approximately 150 additional decontamination methods
- Three additional land use categories: Multi-family residential, lawns and reservoirs
- Surveying and monitoring activities
- Waste disposal operations
- Collective dose avoided by relocating the displaced population
- Collective dose to radiation workers
- Computation of evacuation costs, and temporary and permanent relocation costs
- Capability of defining new land use categories as a linear combination of existing categories

A paramount concern in designing our methodological approach has been the economic consequences of site restoration decisions. The principle that we have strived to apply to all such decisions is that the net present value of the social costs of the accident should be minimized by taking appropriate countermeasures. However, some of the costs, such as those associated with health effects, are not addressed directly by our methodology. Hence, total social costs may not be minimized; but by including all of the important property effects we do minimize at least a major subset of them.

One advantage of this approach is that it 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 decision maker may wish to consider closely the tradeoff between the cleanup criteria and the site restoration costs before finalizing the cleanup criteria. A new capability of DECON is to provide a cost/risk analysis which makes this relationship explicit. It is anticipated that this feature will encourage the use of cost/risk evaluations in the decision process.

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 with losses to society in the billions of dollars. In view of this and in addition to the health issues, two central concerns would likely emerge: 1) recovery costs would need to be kept manageable, and 2) personnel and equipment that are available in relatively abundant supply should be utilized so that the recovery process would not be delayed. Consequently, our approach was to search 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 some information on the decontamination efficiencies of various 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.

### 1.4.1 The Reference Database

The next logical step was to prepare an inventory of decontamination procedures and to identify the surfaces to which they could be applied. Well-defined procedures for decontaminating surfaces are called *decontamination operations* in this report. Table 1.1 presents a list of the operations

- User-selectable output units (U.S. standard units and International System of Units (SI))

- On-screen "Help" messages

- Cost/Risk Analysis - Produces output relating the cost per fatality avoided as a function of the cleanup level

- Capability of producing complementary cumulative distribution functions (CCDFs)

- Master menu for selecting among the major software programs

- Single step installation program

- User's Manual with exercises and detailed explanations

- User friendly program for preparation of the Site Database

- User friendly program for modification of the Reference Database

Revisions

- Number of autos to be decontaminated is now a function of the number of households, the time of day, and whether the accident occurs on a weekend or weekday.

- Output values are now reported in scientific notation

- Menu designs are more attractive and prompts are easier to understand

## 1.4 METHODOLOGY AND OVERVIEW

The Chernobyl accident as well as research that PNL has conducted on off-site accident consequences clearly show that decontamination costs and property losses can range into the billions of dollars and account for the major share of all off-site costs. Site restoration decisions can therefore have major economic consequences. Selection of the cleanup criteria is one such decision, but there are a number of others as well, such as whether to decontaminate unpopulated wooded areas or instead restrict access to them.

Table 1.1. Decontamination Operations and Associated Symbols

| Symbol | Operation | Symbol | Operation |
|---|---|---|---|
| A | Plow | X | Scrape 10 to 15 cm and Remove |
| B | Vacuum Blast | Y | Deep Plow |
| C | Strippable Coating | Z | Remove Structure |
| D | Defoliate | a | 15 cm Asphalt Layer; Add 30 cm Soil (No Trees) |
| E | Leaching, EDTA | | |
| F | Foam | b | Wash; Wipe |
| G | 7.5 cm Asphalt Layer; Add 15 cm Soil (No Trees) | d | Dust |
| | | e | Tack Coat |
| H | High Pressure Water | f | Sealer Coat |
| I | Steam Clean | g | Add 15 cm Soil (Trees in Place) |
| J | Wash and Scrub; Shampoo Carpet | h | Hand Scrape |
| K | Resurface | i | Ion Exchange |
| L | Leaching, $FeCl_3$ | k | Machine Copy Printed Matter |
| M | Close Mowing | n | Spray Solvent |
| N | Clear | o | Vacuum Paper in Place |
| O | Plane, Scarify; Radical Prune | p | Vacuum Exposed Paper Surfaces |
| P | Thin Asphalt/Concrete Layer | q | Vacuum Individual Pages |
| Q | Very High Pressure Water | r | Drain Reservoir |
| R | Remove and Replace | s | Steam Clean Fabrics |
| S | Sandblasting | t | Fixative, Aerial Application |
| T | Surface Sealer; Fixative | v | Double Vacuum |
| U | Hydroblasting | x | Double Scrape |
| V | Vacuum | y | Dredge |
| W | Low Pressure Water | z | Remove Interior, Clean, Replace |

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 |

currently implemented and the symbol for each. Where a symbol is used to describe distinctly different operations, the actual operation should be clear from the surface on which it is used. The operations for automobiles are separately identified for clarity.

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

In decontaminating a surface, it seems appropriate 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 be cost-effective to vacuum it first. Similarly, it may be cost-effective first to apply a fixative and then to clear vacant land before scraping soil from it.

Table 1.2. Surface Types/Categories Implemented by DECON

| Surface No. | Surface | Surface No. | Surface |
|---|---|---|---|
| 1. | Agricultural Fields | 16. | Interior Walls, Wood/Plstr |
| 2. | Orchards | 17. | Interior Walls, Concrete |
| 3. | Vacant Land | 18. | Interior Glass |
| 4. | Wooded Land | 19. | Floors, Carpeted |
| 5. | Streets and Roads, Asphalt | 20. | Floors, Linoleum |
| 6. | Other Paved Surfaces, Asphalt | 21. | Floors, Wood |
| 7. | Streets and Roads, Concrete | 22. | Floors, Concrete |
| 8. | Other Paved Surfaces, Concrete | 23. | Hard-Surface Furnishings |
| 9. | Lawns | 24. | Soft-Surface Furnishings |
| 10. | Reservoirs | 25. | Electronic Equipment |
| 11. | Roofs | 26. | Paper Products |
| 12. | Exterior Walls, Wood | 27. | Auto Exteriors |
| 13. | Exterior Walls, Brick | 28. | Auto Interiors |
| 14. | Exterior Walls, Concrete | 29. | Auto Tires |
| 15. | Exterior Glass | 30. | Auto Engine and Drive Train |

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 data on decontamination methods. An important characteristic of this database is that it can be applied to nearly any radiologically contaminated site without alterations to its data contents. The contents of the Reference Database are described in the next chapter, along with the assumptions underlying it.

### 1.4.2 The Site Database

The Site Database contains information specific to the contaminated site. To conduct a decontamination analysis, five types of information must be provided for each grid element:[1]

- population
- area and type of property that is contaminated
- degree to which the property is contaminated
- value of the affected property.
- employment data by major sector.

These information requirements are addressed in greater detail in Chapter 3. However, there is one aspect of this topic that pertains to the methodology. The approach described in this report requires the analyst to characterize the contaminated areas in terms of land uses, but the decontamination analysis is conducted on the surface categories shown in Table 1.2. Therefore, to implement this approach a mechanism is needed to transform the land use data into data on the surface categories. The mechanism that has been developed for this purpose 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, linoleum 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 are developed in Appendix E.

Besides collecting data on the accident area, there is another task relating to the Site Database. This is to select an appropriate grid arrangement; i.e., to partition the accident area into a number of subareas, or grid

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[1]Employment data are only required if estimates are to be obtained for evacuation costs and temporary and permanent relocation costs.

elements. We assume that each partition or grid element has the following two characteristics: throughout each grid element 1) like surfaces are contaminated to the same level; and 2) each type of property has approximately the same value per unit land area. The procedure for defining the grid element boundaries should be guided by these two criteria. With these criteria in mind, we consider five different ways of partitioning the contaminated area into grid elements. The first four are: 1) a grid with elements of identical size and shape; 2) a radial grid; 3) a grid with elements defined by the boundaries of the radiological isopleths; and 4) a grid with irregularly shaped grid elements whose boundaries may be coterminous with those of political subdivisions. The last two arrangements can be combined into a fifth type, in which grid element boundaries are comprised of both subdivision boundaries and the radiological isopleths. The advantages and disadvantages of each of these arrangements are discussed in Chapter 3.

### 1.4.3 DECON

DECON is a computer program that takes the information in the Reference Database 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 appears in Chapter 4.

### 1.4.4 A Decontamination Analysis of the Indian Point Reactor Site

In Chapter 5 we conduct a detailed analysis of several accident scenarios at the Indian Point reactor site, which is situated 40 km north of New York City. The purpose of this chapter is to illustrate the uses of DECON and the interpretation of its output. The results that are reported should not be considered as representative of reactor accident consequences either for pressurized water reactors (PWR) in general or for the Indian Point reactors, since the plume direction was selected to maximize the off-site accident consequences in an area having a particularly high population density.

# 2.0 THE REFERENCE DATABASE

In this chapter we describe how the Reference Database was developed. Earlier we 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 by making several types of choices. First, a procedure must be selected for decontaminating each surface. The choice will depend in large part on how little residual contamination will be allowed to remain, the effectiveness of the procedure in removing contamination, and the cost of applying the procedure. Generally, the least costly method that reduces contamination to any level at or below the permissible level will be the preferred choice. However, other factors may also need to be considered. For example, the procedure may rely on specialized equipment that is not available in sufficient quantities. Or water runoff from certain decontamination procedures 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 cleanup decision relates to how quickly decontamination operations should be initiated. At least five factors affect this choice. Radioactive decay and weathering act to reduce effective exposure, thus enabling cleanup requirements and costs to decline over time. On the other hand, while the property is awaiting decontamination it cannot usually be used. Deferring the 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. Two other factors that may diminish the value of the property over time are physical deterioration and obsolescence. Depending upon the relative importance of each of these five factors, social costs may sometimes be minimized by deferring decontamination operations for some specific period of time.

In addition to the factors mentioned, there are other considerations that may affect site restoration. For example, except in unusual circumstances, it will generally be impractical to decontaminate a property if the surrounding property is allowed to remain contaminated over an extended period of time. Another example relates to the political pressure that will be brought to bear by those suffering property losses. There will be pressure to decontaminate the property as quickly as possible, especially if the decontamination costs will not be borne directly by those owning the contaminated property.

A decision also must be made regarding how completely the contaminants are to be removed; i.e., selection of the cleanup level. While the current approach does not directly select the cleanup level, it does produce information on the relationship between site restoration costs and health risks from residual contamination. Generally, it becomes increasingly more costly to avoid a given increment of additional health risk from residual contamination. Thus, the selection of the cleanup level can be based on the increasing cost of reducing the health risks.

## 2.1 CONTENTS OF THE REFERENCE DATABASE

To implement the approach described above and thus 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 (dollars per unit area decontaminated)
- efficiency of each decontamination method (percent reduction in committed dose to individuals)
- coverage rate of each decontamination operation (area decontaminated per shift-hour)
- physical inputs to each decontamination operation (hours of labor and equipment and quantity of material, per unit area)
- volume of radiological waste generated by the decontamination operation (volume units per unit area covered).

Throughout this report we use the term *operation* to refer to a well-defined, single decontamination procedure applied to a single surface type. Examples are vacuuming pavement and hosing roofs. However, some operations may 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. The steps involved in the various operations are described in Appendix A.

One or more operations executed on a single surface type constitute a *method*. For example, the operation of vacuuming pavement followed by the operation of resurfacing the pavement is a method. This designation is important because the order of the operations comprising a method determines the net decontamination efficiency; reversing the order of the operations is likely to result in a different 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 sq meter, the average number of sq meters decontaminated per hour, and the composition of cost in terms of physical inputs are presented for each operation. In addition, some of the efficiencies of the operations are briefly indicated for both the inhalation and external pathways, which are separated in the text with a slash (/). A complete set of the efficiencies for all methods is presented in Appendix B.

### 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 cost estimates. The costs refer only to the direct costs of actual decontamination activities. 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 potential health costs to workers.

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 depend in large measure on how far the contaminated materials must be transported, and because this distance is likely to vary from situation to situation, transport costs are not included in the cost estimates of the operations.[1] However, the Reference Database does contain sufficient information to enable the transportation costs to be estimated.

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[1]However, in some of the output reports, which are discussed later, the costs for transporting and disposing of radiological wastes are combined with the direct decontamination costs.

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 away the radioactive waste. 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 type under consideration. In practice, the contaminants originally on a surface may be transported to surrounding surfaces. This phenomenon may occur either prior to decontamination--through resuspension or transport via a host such as a vehicle traveling along a roadway. Or it may occur during the decontamination process itself--again through resuspension or transport.

For example, consider treatment costs for roofs being decontaminated with low-pressure water. The contaminants become entrained in the water, but we include no costs 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 acceptable in some situations; in other situations, the runoff might need to be collected in drums via a permanent or temporary 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 cost estimates 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 and evaluated.

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 been transported. 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 accident 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.

In practice, 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. In addition, it is generally advisable to decontaminate surrounding lawns and pavements only after roofs have been treated, and to decontaminate downwind areas only after treating upwind areas.

The costs that have been developed for all of the operations are based on the assumption that very large areas are to be decontaminated. This implies that all economies from large-scale operations are fully exploited. For example, the costs used in most cases for materials reflect large-quantity discounts. In addition, the costs for mobilizing and demobilizing manpower and equipment are assumed to be a negligible portion of the total costs of an operation and are therefore not included in the cost estimates. If, on the other hand, only small areas need to be decontaminated, a premium should be added to the costs to reflect the scale of operations with adjustments for mobilization and demobilization.

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. In situations requiring personnel to wear anti-c's or other protective gear, time must be taken out of every work shift for clothing changes and personnel decontamination procedures. Equipment will also need to be decontaminated periodically, and probably frequently. The cost estimates for labor and equipment include one hour per eight-hour shift to account for these radiation control measures. This is an average value; it assumes that the treatment of large areas near the outer boundaries of the decontamination zone will require no protective gear and few other radiation control measures.

A second reason that the cost of working in a contaminated environment will be higher is that protective clothing will reduce worker productivity, which in turn will increase decontamination costs. This will be particularly true in warm or hot weather. The cost estimates have not been adjusted for this effect.

A third reason is that workers will likely demand a premium to work in a contaminated environment because of real or perceived health consequences. 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. When using the Reference Database, the cost data should be adjusted by using an appropriate price index to adjust to *current* price levels. In Table 2.1 we present Gross National Product (GNP) Implicit Price Deflators for periods beginning in 1982. Deflators are given for Durable Goods, Nondurable Goods and Services. The deflators for durable goods are appropriate for adjusting equipment costs; the deflators for nondurable goods are appropriate for adjusting the cost of materials; and the deflator for services is appropriate for adjusting labor costs. To adjust a cost category, simply multiply the 1982 costs by the entry in Table 2.1 and then divide by 100. For example, to adjust manpower costs to fourth quarter 1986 dollars, multiply all manpower costs by (124.3/100) = 1.243.

The information in Appendix A details how the costs of all the operations were developed. In many cases, the information underlying these costs shows significant variation, and in a few cases the information is even inconsistent. Consequently, a considerable degree of judgment had to be exercised in the selection of representative costs.

## 2.3 PROCEDURES FOR INTERDICTED AREAS

In interdicted areas it will usually be good practice to apply a fixative to all exterior surfaces to prevent decontaminated areas from becoming recontaminated. Aerial application of the fixative appears to be the most practical method to accomplish this. Road oil is one type of fixative, and other types are discussed in Appendix A, Section A.1.1.2.

The application of road oil by aircraft requires an airfield with facilities to perform routine airplane maintenance and to rapidly load high volumes of road oil onto the planes. Both large planes such as DC-7s with an 11.4-kiloliter (3000-gallon) capacity and small planes with a 1.3-kiloliter (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 1.5 liters per sq meter should provide a relatively uniform coating. The cost of aerial application at this coverage rate ranges from $0.11 to $0.24 per sq 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 sq meter to $0.42 to $0.55. The expected cost is therefore about $0.45 per sq meter. The rate of application will be from 1,808 to 16,461 sq meters per hour, again depending on the type of aircraft used. A rate of 14,000 sq meters per hour is assumed, since a larger aircraft is more likely to be used.

Table 2.1. Implicit Price Deflators for Gross National Product(a)

| Period | Durable Goods | Nondurable Goods | Services |
|---|---|---|---|
| 1982 | 100.0 | 100.0 | 100.0 |
| 1983 | 102.1 | 102.1 | 106.2 |
| 1984 | 103.8 | 105.0 | 111.7 |
| 1985 | 104.5 | 107.5 | 117.3 |
| 1986 | 105.3 | 107.0 | 122.4 |
| 1982 IV | 100.7 | 101.0 | 102.7 |
| 1983 IV | 103.1 | 103.1 | 108.3 |
| 1984 I | 103.3 | 104.4 | 109.6 |
| II | 103.9 | 104.5 | 110.9 |
| III | 104.1 | 105.1 | 112.4 |
| IV | 104.1 | 105.8 | 113.5 |
| 1985 I | 104.6 | 106.3 | 114.8 |
| II | 104.5 | 107.4 | 116.3 |
| III | 104.6 | 107.6 | 118.0 |
| IV | 104.3 | 108.6 | 119.4 |
| 1986 I | 104.5 | 107.8 | 120.7 |
| II | 104.6 | 106.2 | 122.0 |
| III | 105.4 | 106.8 | 123.3 |
| IV | 105.2 | 107.5 | 124.3 |
| 1987 I | 105.4 | 109.8 | 125.5 |
| II | 106.1 | 111.7 | 126.9 |
| III | 107.4 | 112.6 | 128.3 |
| IV | 107.5 | 113.6 | 129.8 |

Source: Economic Indicators. Prepared for the Joint Economic Committee, 100th Congress, First Session. February 1988. U. S. Government Printing Office.

(a) The Implicit Price Deflators are given for three categories: Durable Goods, Nondurable Goods, and Services. These categories correspond most closely to the respective categories of Equipment, Materials, and Labor.

## 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 at the end of each subsection. The information in this chapter is provided in much greater detail in Appendix A.

### 2.4.1 Land Surfaces

The land surfaces category consists of agricultural fields, orchards, vacant land, wooded land, asphalt and concrete streets and roads, other paved surfaces, and lawns.

There are four subcategories of paved surfaces. *Asphalt roads* and *concrete roads* refer respectively to large areas paved with asphalt and concrete. In addition to highways, streets and roads, these subcategories include large commercial parking lots and other large paved areas such as loading dock areas. The other types of paved surfaces are designated here as *other asphalt* and *other concrete*. These subcategories represent surfaces that cover relatively small areas to which access may be limited. Surfaces in this subcategory include patios, residential driveways, and carports. Because such surfaces are not amenable to high production rate techniques, the costs of operations are higher than for the corresponding operations applied to road surfaces.

The decontamination costs for these land surface subcategories are described below.

#### 2.4.1.1 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. However, this is appropriate only if underground water supplies will not be materially contaminated and plants will not become a health hazard by uptaking contaminants through their root systems. 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 is based on using a tank truck with spreader or spray capability.

There are a variety of fixatives appropriate for use on soil. Section A.1.1.2 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 is applied using a tank truck with liquid spray capability.

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

Scraping involves removing the top 10 to 15 cm of the soil surface. This generally follows the application of a fixative or water to minimize resuspension of radioactive particles during scraping. This operation utilizes standard earthmoving equipment such as front-end loaders. Dump trucks are used to haul away the scraped soil. (Hauling is treated separately throughout this report, because 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 this operation.)

In their study of decontamination techniques and efficiencies, Dick and Baker (1961) found plowing to be very effective against inhalation exposure. 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 (assuming an irrigation system is not available for the application of water). The reason for this low cost is the ability of mechanized farm equipment to treat large areas rapidly. Further, cost estimates are 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 25 or 30 cm deep, special equipment can achieve much greater penetration. Deep plowing has the potential to mix or turn soil to a depth of over 90 cm. One source reported the ability to plow to a depth of 1.5 meters through very hard soil. Because the coverage rate for deep plowing is relatively high, the cost per sq 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 used to harvest or otherwise treat the crop may provide the best means for clearing. The cost estimate here is based on using a swather to remove a corn crop.

Covering the ground with 15 cm of uncontaminated soil may be performed alone or after scraping. In any case, covering provides both shielding and protection against inhalation. The costs and rates of operations on agricultural fields are summarized in Table 2.2.

#### 2.4.1.2 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 contaminants 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 care taken to avoid damage to the trees will often impair the speed, effectiveness, and choice of decontamination operations. The trees limit the type, size and the maneuverability of the equipment.

The cost of low-pressure water is based on the assumption that flood irrigation is available. Consequently, it is very inexpensive.

Application of a fixative is considered from two perspectives. First, an aerial application deposits the fixative primarily on those foliage surfaces that received the most contamination. In addition, a fixative applied from the ground is directed toward the branches and trunks of the trees and to

Table 2.2. Summary of Representative Cost and Productivity Data for Agricultural Fields Decontamination Operations

| Operation | Rate(a) ($m^2$/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, FeCl3 | 1,814 | 0.052 | 0.0109 | 0.0151 | 0.026 |
| Scrape | 875 | 0.31 | 0.13 | 0.18 | -- |
| Plow 25 to 30 cm | 6,374 | 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 | -- |

(a)The suggested precision of the rate data here and elsewhere in this report is misleading. For the most part, these numbers have been converted from U.S. Customary Units to metric values. Rather than rounding the converted values, they are presented as calculated.