step is to partition the accident zone into a grid. Each partition or grid element is assumed to have the following two characteristics: 1) each surface has the same contamination level throughout the grid element; and 2) each type of property has the same value per unit land area throughout the grid element. The process of defining the grid element boundaries should be guided by these two criteria.

The analyst may choose among five different ways to partition the accident area. The first four are: 1) a grid with elements of equal size and shape (rectangular grid); 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 arrangement are discussed below.

Keep in mind that data have to be developed for <u>each</u> grid element when deciding on the type of grid arrangement to be used.

3.3.1 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 decreased by increasing the size of the grid element. However, a rectangular grid arrangement is probably most useful when preparing a detailed restoration plan, which will focus on individual buildings or city blocks.

Land use data will probably not be directly available for rectangular grid elements, but will likely have to be developed from land use maps, such as those published by the United States Geological Survey, or from direct observation. The 7-1/2 minute series maps show individual houses and business establishments. Unfortunately, small business establishments are not distinguishable from residences, and large multi-family establishments are indistinguishable from other large buildings.

Knowledge of the location of individual buildings can also be an aid in estimating the population within each grid element. If the grid elements are fairly large, then IR-GRID can be used to impute data from political subdivisions to the grid elements; however, in this case, it probably makes more sense to base the grid elements on the boundaries of the subdivisions, as explained below.

If the grid element size is very small, property tax information may have to be obtained from property tax rolls or from a similar source. If the grid elements are very large, property values for selected counties are published in "Taxable Property Values and Assessment Sales-Price Ratios" (Census of Governments, 1982).

3.3.2 Radial Grid

The problems associated with collecting data for a rectangular grid are, for the most part, also to be found with a radial grid. The advantage of using a radial grid relates to its improved accuracy in assessing the overall consequences of the accident. 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.

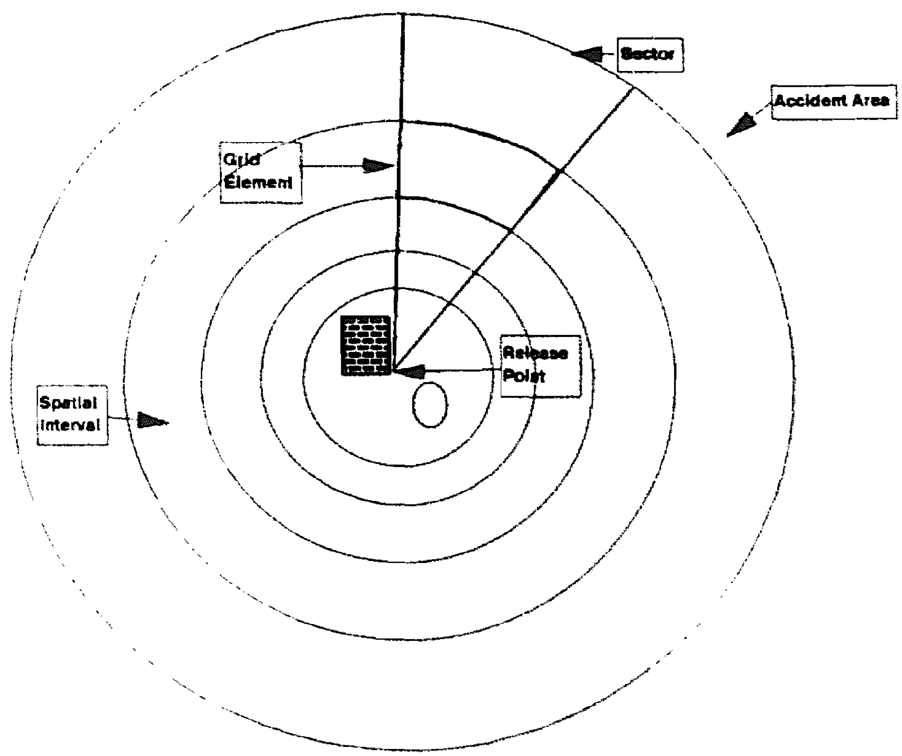

Figure 3.1. Typical Radial Grid Geometry

For the more severe reactor accidents in which the plume spans several political subdivisions, the IR-GRID program provides an attractive option. As already noted, this software will impute data values to the grid elements based on data obtained for political subdivisions.

3.3.3 Grid Elements Bounded by the Radiological Isopleths

For simulated accidents or actual accidents, a set of radiological isopleths can be made available to the analyst. This choice of grid element arrangement is perhaps the easiest way to meet the requirement that all of the land within a grid element is contaminated to the same degree. In this arrangement the area between each pair of radiological isopleths becomes a grid element. These grid elements can then be further subdivided to satisfy the property value requirement.

All of the difficulties discussed above relating to imputing land uses and property values to the grid elements are involved here as well. In addition, because of the irregularly shaped grid elements, obtaining the areas of the grid elements requires an additional effort. Using a planimeter to compute the areas is the best method, although "counting the squares" within each grid element will also provide a reasonably accurate estimate. In this latter technique, a gridded overlay is superimposed on each grid element. The number of squares falling within each grid element times the area represented by each square gives the desired result.

3.3.4 Irregular Grid Based on Political Subdivision Boundaries

A fourth 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 sq kilometers, then as one goes beyond, say, 80 or 100 kilometers 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 for the area within a few miles of the release point. In this case, one can assume that all subdivisions of a township or county have the same characteristics, except for the contamination level, or one can

provide more precise information if it is available. The U.S. Geological Survey 7.5 minute series maps mentioned earlier can be used to provide estimates of population, land use and property values for these partitions.

The second potential disadvantage is determining the dose or ground concentration for each of the grid elements. For an actual accident, the problem is solved by having the radiological survey team provide a reading at or near the center of the grid element. However, for a simulated accident, the GRID program described in Appendix E, Section E.2, can be used to obtain an estimate of the dose or ground concentration at any point downwind from the release point.

3.3.5 Irregular Grid Based on Political Subdivision Boundaries and Isopleths

This grid arrangement is similar to the one described above except that it provides additional resolution with respect to contamination levels. In this arrangement each grid element boundary is coterminous with both relevant political subdivision boundaries and isopleth boundaries. The effect is to further subdivide each political subdivision into a number of grid elements equal to one more than the number of isopleths passing through it. For example, if three isopleths pass through a subdivision, then this subdivision will consist of four grid elements. To provide data for each grid element, the simplest approach is to assume that each grid element takes on all of the characteristics of the political subdivision except for the ground concentrations which are, of course, determined by the isopleths.

4.0 DECON--A COMPUTER PROGRAM TO ESTIMATE THE PROPERTY-RELATED COSTS OF SEVERE RADIOLOGICAL ACCIDENTS

In this chapter we describe the decontamination analysis program called *DECON*. This program was developed with two aims in mind: 1) to provide estimates of the property-related costs of severe reactor accidents; and 2) to assist in site-restoration planning. DECON utilizes the Reference Database and the Site Database described in Chapters 2 and 3 of this report. DECON can operate either in interactive mode on an IBM Personal Computer and compatibles, or in batch mode on a VAX Computer. The current version (Version 4.0) for use on a microcomputer requires a minimum of 256K RAM, a math coprocessing chip and two disk drives; a hard drive is recommended but not required.

4.1 LOGICAL STRUCTURE OF DECON

In this section we consider the logical structure of DECON. DECON's operating principle--to minimize the off-site economic costs of the reactor accident through site restoration actions--is described, and the underlying assumptions are discussed.

4.1.1 Minimizing Economic Costs Through Site-Restoration Actions

The process by which DECON minimizes the economic or social costs of the accident is relatively straightforward. 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 restorative actions are taken. All of the adjustments are social costs attributable to the accident. These adjustments are described below.

If an asset becomes contaminated so that it cannot be used for some period of time, then the owner of the asset will suffer a loss. The loss, in fact, will be identical to the *ownership costs* during the period that the asset remains out of use[1]. To see this, observe that *acquisition costs* must

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[1]The costs associated with an asset can be viewed in terms of three components: the acquisition costs, the ownership costs, and the operating costs. *Acquisition costs* consist of the purchase price plus any depreciation that cannot be avoided by immediate resale. *Ownership costs* include depreciation due to asset deterioration and to changes in asset value due to altered market conditions, including those giving rise to technological obsolescence.

be excluded since they have already been incurred--i.e., they are sunk. *Operating costs* are excluded simply because they are avoided while the asset remains idled. Finally, since the asset will have no value in use during the period that it is idled--i.e., its rental value during this period is zero--the losses must include all of the ownership costs incurred during this period[2]. We now consider five types of ownership costs that apply to property that has been radiologically contaminated. They are property losses due to:

- residual contamination
- deterioration
- altered market conditions
- deferred use
- decontamination costs

We now consider these effects of the accident and the property value adjustments that DECON makes for them.

4.1.1.1 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 less will be the residual contamination. However, irrespective of how little residual contamination remains, the public may perceive some health risk remaining from the decontaminated property. In addition, the extent of the perceived health risk is likely to depend upon the way that the property is used. For example, residential property values may be more adversely affected than industrial property values, and agricultural land values more adversely affected than either of these. Because there is no clear evidence on how much property values would fall under various cleanup criteria, and because this effect could vary by country and by region, DECON allows the analyst to select a set of residual contamination factors--one factor for each land use category.

Ownership costs arise even if the asset is never put into use. *Operating costs* are incurred only by using the asset; they include depreciation due to wear and tear, maintenance costs, and other costs of operation such as fuel use.

[2]Although taxes are a part of private ownership costs, they should not be included here, since social rather than private costs are being evaluated.

Residual contamination factors provide for a one-time loss in property values. DECON adjusts property values for residual contamination as follows. If k is the residual contamination factor, and V_o is the real property value prior to the accident, then the post-decontamination real property value, V_t, is

$$V_t = (1-k) \cdot V_o \qquad (1)$$

As mentioned earlier, the magnitude of k is expected to depend on the type of property, and to vary with the cleanup level, since the cleanup level determines the quantity of residual contamination.

4.1.1.2 Deterioration and Obsolescence

Ownership costs include the effects of obsolescence and deterioration. Both effects could be quite substantial if the property is neglected for several years while waiting to be decontaminated. As with residual contamination, 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; however, deterioration may be at the same rate. On the other hand, vacant land would neither deteriorate nor become obsolete.

In developing an estimate for deterioration losses, it is important to keep in mind that the pre-accident value of the property likely assumes a regular maintenance schedule. Since maintenance may be postponed while the property is contaminated, the maintenance costs are avoided. Thus, the losses due to deterioration need to be reduced by these avoided maintenance costs.

To account for losses due to deterioration and obsolescence, DECON permits the analyst to select a set of factors--one for each land use category. These factors express the annual percentage rate of property loss due to deterioration and obsolescence. The loss is calculated for each year that the property remains idled and is computed separately for each land use category. DECON uses the following formula, which computes the combined effects of deferred use and deterioration/obsolescence for real property. If the property has a value V_t, after accounting for the loss from residual contamination, then after t years of deferred use and deterioration and/or obsolescence, the value of the property will be

$$v_R = \text{MAX}\ [V_t \cdot \exp\{-(r+df) \cdot t\},\ S] \qquad (2)$$

where **df** = the annual depreciation factor due to deterioration and/or obsolescence, **r** is the discount rate, and **S** is the discounted scrap value of the property at the conclusion of its useful economic life. The value for **df** is expected to depend on the type of property; and **S** is assumed to have a value of zero.

4.1.1.3 Altered Market Conditions

Still another source of potential property loss relates to altered market conditions that can give rise to ownership costs. This category encompasses many kinds of effects on both the supply and demand sides of a market. For example, consider a local food processing industry whose operations are no longer viable within the local community. As a result of the closure of these plants, all real estate values within the local area may suffer a permanent decline, apart from their decline due to direct contamination.

As another example, consider a large production center that is so badly contaminated that decontamination cannot take place soon after the accident. The center may suffer a permanent loss of its skilled labor force which can cause a general population decline, diminished economic activity in the area, and a consequent decline in property values.

To incorporate the effects of altered market conditions on ownership costs, **df** and $\mathbf{V}_t$ may be adjusted in the previous equations. **df** should be adjusted if the effect on ownership costs is best characterized by a constant annual percentage change, while $\mathbf{V}_t$ should be adjusted if the effect is best characterized as a one-time change. If the expected change varies from year to year, then **df** can be used, but the analyst will first need to compute the single rate that is equivalent to the series of rates. This computation can be made using levelized cost relationships.

4.1.1.4 Deferred Use of Property

Property can be viewed as providing a flow of services to its owner or user. The current value of a property is equal to the net present value of the expected flow of these services over the lifetime of the property, less any scrap value that the property may have at the end of its useful life. If the flow of services from a property becomes interrupted, the property will therefore lose some of its value.

Property that becomes contaminated may be taken out of use until it can be restored. The deferral or loss of its services constitutes a fourth factor affecting its value. The loss from the deferred use of *real property* is estimated implicitly in combination with the losses from deterioration and obsolescence; the formula was given in Equation (2) above. The current value of *personal property* that will be out of use over the next **t** years is given by

$$PP_C = PP_P \cdot \exp\{-r \cdot t\} \quad (3)$$

where **r** is the real rate of discount, and $\mathbf{PP_P}$ is the pre-accident value of personal property. The pre-accident value of personal property is user-selectable, with a default value of one-half of its estimated replacement cost. Personal property is assumed not to suffer losses due to residual contamination or deterioration.

4.1.1.5 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 incurred in year **t** are **C**, and **r** is the discount rate, then the net present value of the decontamination costs is

$$C^* = C \cdot \exp\{-r \cdot t\} \quad (4)$$

If we now put these relationships together to determine the present value of a property, **V***, that remains out of use for **t** years and suffers from residual contamination, deterioration and obsolescence, deferred use and the costs of surveying, monitoring and decontamination, we have

$$V^* = V_o \cdot (1-k) \cdot \exp\{-(r+df) \cdot t\} + PP_P \cdot \exp\{-r \cdot t\}$$

$$- (D_R+D_B+D_A) \cdot \exp\{-r \cdot t\} + SM \quad (5)$$

where $\mathbf{D_R}$ is the cost to decontaminate real property; $\mathbf{D_B}$ is the cost to decontaminate building contents; $\mathbf{D_A}$ is the cost to decontaminate automobiles; **SM** is the net present value of the cost of all surveying and monitoring activities; and the other variables are as previously defined. The factors affecting

residual contamination (**k**), deferred use (**r**) and, deterioration (**df**) are separately identifiable in Equation (5). Each factor can be altered in DECON to determine the sensitivity of the results to any or all of them. Furthermore, other effects, such as inventory and crop losses, effects from altered market conditions, and property hazard risks can be embedded in either the annual deterioration factors, or the one-time residual contamination factors, whichever is appropriate.

4.2 MINIMIZING PROPERTY RELATED LOSSES

In this section we consider the explicit process by which DECON minimizes the costs of the accident, some of its major assumptions, and several property concepts developed by the model.

4.2.1 Algorithm to Maximize Property Values

The algorithm upon which DECON is based works to maximize **V*** (which is the same as minimizing the off-site costs of the accident) by varying decontamination costs, **C**, and the 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

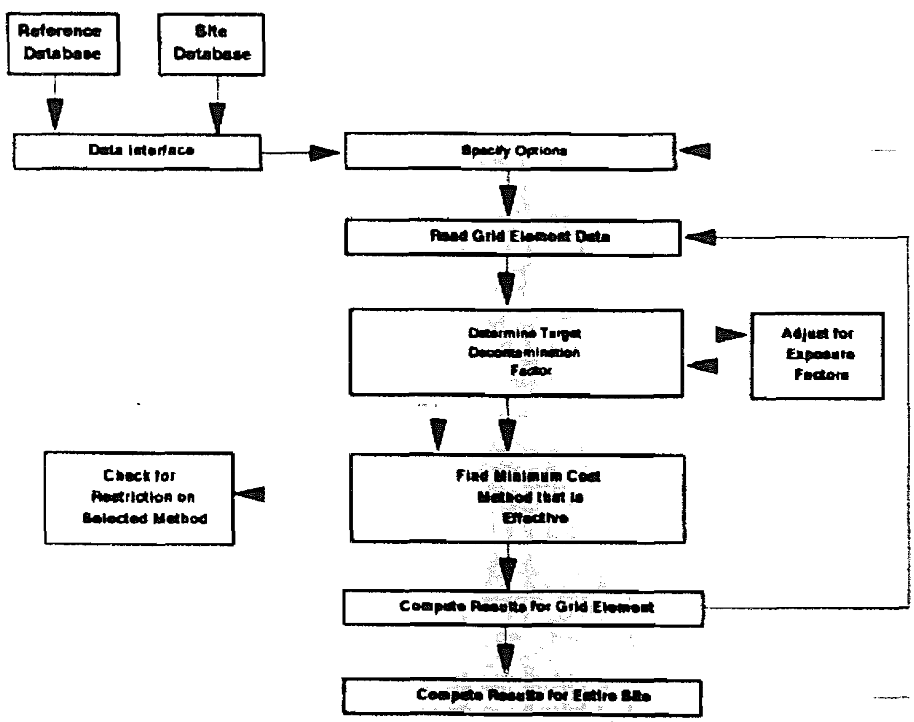

FIGURE 4.1. Primary Logic of DECON

decontamination activities take place and all costs are incurred on an anniversary date of the radiological release. However, violation of this assumption will not significantly affect the results.

If an area needs to be decontaminated, it is assumed that it will be at least a year before it is decontaminated. Therefore, the radionuclides are allowed to decay and weather for a year before the analysis begins. The CRAC2 weathering and decay models are used to develop a set of weathering and decay factors, which are read into DECON. One factor is required for each of the 30 time periods used in the analysis.

Although the data are collected in terms of land uses, DECON receives the information in terms of surfaces. The land uses are transformed into surface categories by SD-INPUT or IR-GRID, the programs for processing the Site Database. This procedure is explained in Chapter 3 and Appendix E. The steps taken by DECON are as follows. The first grid element is selected, and the surfaces within that grid element are sequentially processed. For the first surface, a target decontamination factor is calculated[3]. 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[4].

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[3]A *decontamination factor* is defined as one plus the ratio of removed contamination to residual contamination, where contamination is measured in terms of dose rate, dose commitment or other similar measure. The *target decontamination factor* is simply the factor by which the dose measure must be reduced to just equal the cleanup criterion.

[4]This discussion describes the logic underlying DECON. DECON itself actually follows a somewhat different logic, which enables it to process the results more quickly.

4.2.2 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 deterioration, deferred use, and residual contamination. If none of the surfaces within the grid element requires decontamination, it is assumed that none of the property loses value.

4.2.3 Property that Cannot Be Decontaminated

A different situation which may arise is that a surface within a grid element may be so severely contaminated that none of the methods in the Reference Database is sufficiently powerful to successfully decontaminate it. 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, at a given time, one or more surfaces within a grid element cannot be decontaminated, none of the surfaces within the grid element are decontaminated at that time[5]. Cars and building contents are exceptions, since they can be readily removed from the grid element.

Another exception occurs if only a single-period analysis is selected. In this case, DECON indicates which surfaces can and which cannot be decontaminated.

4.2.4 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 highest algebraic value for V^* is negative. In other words, if the evaluation is made exclusively on the cost factors considered in the analysis, 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

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[5]In extreme cases, it will not be possible using methods in the Reference Database to decontaminate property within the 30-year period spanned by the analysis.

this with the cost of mitigating the hazard, say, by applying and maintaining a fixative and restricting access.

When the best decontamination solution for a grid element still yields a negative value for V*, a negative net present value is reported at the grid element level. However, in the report summary for all of the grid elements, results are reported in two ways. Under one assumption, the properties with negative present values are assumed not to be restored but interdicted; in this case, the net present value of the property in the study area includes the value only of property in those grid elements that it pays to restore[6]. Under a second assumption, all properties are restored according to the specified decontamination program, irrespective of cost-effectiveness considerations. For clarity, these and other property value concepts that are reported by DECON are discussed in the following section.

4.2.5 Property Value Concepts in DECON

Several different property value concepts are reported by DECON. They are:

- value of real/personal property prior to the accident
- value of real/personal property after decontamination
- the net present value of real property immediately after the accident
- total reduction in the present value of real property
- total reduction in the present value of all property
- magnitude of property-related losses
  - with property buy-out
  - with full decontamination
- total potential savings from real property buy-out
  - at pre-accident property values
  - at net present value of real property

The first concept is the simplest; it refers to the market value of real property (land and structures) or personal property (automobiles and building contents) immediately before the accident threat[7].

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[6]A study area contains all of the grid elements included in an analysis. This may be a subset of the entire accident area.

[7]Property values will decline once a threat to the property is perceived, but before the actual occurrence of the accident.

The next concept relates to the value of real property after decontamination. The property is likely to lose some of its original value because decontamination will not remove all of the radiological contaminants. The amount of loss due to residual contamination is likely to depend on both the type of land involved and the degree to which contaminants have been removed.

The net present value of real property immediately after the accident is affected by several factors. In addition to the previously discussed residual contamination, there are the effects of 1) deterioration due to neglect while the property remains contaminated; 2) the loss of use while the property remains contaminated; 3) the decontamination costs; and 4) the cost of surveying and monitoring activities associated with decontamination. All of these yet-to-occur costs affect the current value of the property, which is discounted to the present using an appropriate rate of discount.

The total reduction in the present value of the real property is simply the pre-accident value of the property less the net present value of the property immediately after the accident. This concept is the capital loss suffered by the owner of the property as a result of the accident. The capital loss can exceed the pre-accident value, since the costs of restoring the property can exceed the post-restoration value of the property.

The total reduction in the present value of all property includes, besides the real property loss, the discounted cost to decontaminate personal property (automobiles and building contents), the discounted loss from the deferred use of personal property, and the discounted costs to provide continuing surveying and monitoring for radiological contamination.

As discussed in the previous section, the magnitude of property-related losses will depend on whether contaminated areas are restored irrespective of cost-effectiveness considerations. If cost-effectiveness criteria apply to cleanup decisions, the loss will equal the capital loss from real property--but not to exceed the pre-accident value of the real property; plus the discounted cost to decontaminate or replace automobiles and building contents; plus the discounted cost to provide continuing surveying and monitoring for radiological contamination. If cost-effectiveness is not a consideration, then the costs to decontaminate and survey the additional grid elements--those that are not cost-effective to restore--must be added.

The total potential savings from a buy-out of real property is considered from two perspectives. First, property can be bought out at the pre-accident value of the property. Typically, this is what happens when property owners are compensated for the losses they incur. This perspective is useful when addressing compensatory issues.

The second perspective relates to measures of social costs. Under this concept property is bought out at the greater of its net present value (post-accident) or zero. The savings from this type of buy-out equal the social costs avoided by restoring only property that is cost-effective to restore. Since this type of buy-out would not usually be considered equitable, it is not used in determining compensation.

4.3 SPECIAL FEATURES

DECON has been designed with several features to facilitate its use in site restoration analysis. To assist the user, DECON is almost entirely menu driven. The user has a choice of several different output formats: Detailed information by surface category can be produced for individual grid elements, or summary data only can be selected. Summaries are for the entire study area and, optionally, for individual grid elements. Other special features are described below.

4.3.1 Subarea Analysis

DECON has the ability to perform a subarea analysis for any grouping of grid elements. For example, if the accident area is characterized by irregularly-shaped grid elements, 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 specified to define the subarea. Grid elements whose numbers are within the interval defined by the pair are included in the subarea. Thus, if the pair [72,79] is specified, grid elements 72,73,...,79 are included. Up to 100 pairs of numbers can be used to define the subarea. This technique proved especially useful when applied to a rectangular grid (see Tawil 1983). In this application a decontamination analysis was conducted for an area of 350,000 sq meters, which was divided into grid elements of size 15 by 15 meters. Several irregularly-shaped subareas representing neighborhoods were analyzed.

4.3.2 Pre-Rain Analysis

If precipitation falls on contaminated surfaces, decontamination may become more difficult and more costly. As a consequence, it is necessary to have separate efficiency estimates for all decontamination methods applied to exterior surfaces, depending upon whether decontamination occurs prior to rain or following rain. Such a distinction allows one to ascertain the potential savings from decontaminating surfaces before they become wet. Although in most circumstances it would be extremely unlikely that decontamination could be completed before the first precipitation, 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 exterior surfaces as well.

Another option involves vacuuming selected exterior surfaces prior to precipitation. Vacuuming is one of the least expensive methods for decontaminating several types of surfaces, and it has a reasonably good removal efficiency. Furthermore, it can be applied over many surface types 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, although the effective rate for vacuuming roofs is estimated at just 81 sq meters per hour, as compared with a rate of 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 on certain surfaces. For example, operations that utilize water on agricultural lands could cause 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 operations 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 operations 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 (see Figure 4.1). If the method is found to contain this operation, it is bypassed for the specified surface(s).

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 to accommodate equipment

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, one can also require DECON to impose a specified method on one or more specified surfaces. As an example, 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 clear the land before it is scraped.

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[8].

The limitation of 100 restrictions per case noted in Section 4.3.3 also includes the number of required methods imposed for any single case. In other words, the maximum number of restricted plus required procedures cannot exceed 100. Also, be aware that while restrictions apply only to operations requirements apply to methods (which include operations). Finally, DECON does not check for inconsistencies; for example, it does not check whether different methods have been specified for the same surface. In such cases, the first requirement entered will be the one that is operative.

4.3.5 Variation in Exposure Levels

Another DECON application is to allow a different cleanup standard to be applied to each surface category, depending, say, on the exposure risk presented by the surface. The potential usefulness of this feature is based on the observation that the risk from exposure to different surfaces varies

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[8]The reader is reminded that the reported efficiencies of the methods may not be very accurate. In many instances they have had to be inferred from indirect evidence.

considerably. Housing interiors, for example, would usually pose a high risk, while highways and wooded areas would tend to pose a relatively low risk.

To implement this concept, the analyst specifies an exposure factor for each surface category. The exposure factor is multiplied in DECON by the specified cleanup level to determine the operative cleanup level for that surface. For example, if the cleanup level is 0.20 Sv, then an exposure factor of 0.5 given to interior walls means that walls would be decontaminated to a level of 0.10 Sv or less; similarly, an exposure factor of 10.0 given to wooded areas means that such areas would be decontaminated to a level of 2.0 Sv or less.

Practical applications for this strategy include 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 put into practice, it would be important to ensure that no individual received excessive exposure from surfaces rated for low exposure. For example, work places might effectively tolerate higher residual levels provided that the time on the premises was limited, say, to eight hours.

4.3.6 Cost-Risk Analysis

Before selecting the cleanup level to be applied to a contaminated site, it is useful to know the relationship between the costs of site restoration and the human health risk posed by the residual contamination. More stringent cleanup levels reduce the health risk, but they will invariably result in higher restoration costs; the converse is also true. DECON allows the analyst to produce a cost-risk evaluation simply by specifying the cleanup levels for which he wants the costs and risks evaluated. The reported statistic is the *incremental cost per fatality avoided* by moving to the indicated cleanup level from the cleanup level immediately below it. For example, if the analyst specified a cost-risk evaluation for cleanup levels of 0.05, 0.10, 0.20, and 0.50 Sv, the incremental cost per fatality avoided for 0.20 Sv would pertain to tightening the cleanup level from 0.50 Sv to 0.20 Sv. Another value would be reported for moving from 0.20 Sv to 0.10 Sv. And a third and final value would be reported for moving from 0.10 Sv to 0.05 Sv. The cost-risk relationships are produced by the PLOT utility (from the main menu) after a cost-risk analysis has been selected and run from DECON.

To compute the health risks, DECON uses a dose-response relationship of 2.0×10^{-2} cancer deaths per person-Sv of exposure; however, this factor can be modified by the analyst.

4.4 COMPUTATIONAL MODELS

This section describes briefly each of the computational models used in DECON.

4.4.1 Contamination Model

It is unreasonable to expect that all surfaces will receive the same mass loading of contaminants from deposition of the plume. In particular, vertical walls and interior surfaces will become less contaminated than horizontal, exterior surfaces in the same vicinity. As a percentage of the mass loadings of contaminants on a unit area of horizontal, exterior surfaces, DECON assumes the following values for these other surface categories:

- exterior vertical walls receive 10 percent
- interior floors receive 50 percent
- interior vertical walls receive 5 percent
- automobile interiors receive 30 percent

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 a study by Alonza et al. (1979); the other two figures are based on the authors' judgment.

As already noted in the discussion on efficiencies (see Section 2.8 and Appendix B), contamination levels are based on the mass loadings of radioactive contaminants at the time of the plume passage. Subsequent transmigration of contaminants is ignored. However, it was suggested that at least some of the effects of transmigration would be mitigated by effective decontamination strategies.

4.4.2 Population Dose

A useful concept in planning a site restoration strategy is the population dose avoided by mitigating actions. The primary mitigating action is the relocation of the population starting from the time individuals would have returned from evacuation and temporary relocation (assumed to be 14 days) and lasting until the site can be restored to the selected cleanup level. The following relationship is used to compute **d**, the population dose avoided through relocation:

$$d = pop \quad C \quad SF \quad (1.0 - CD_t) \tag{6}$$

where

pop = the affected population

C = 70-year committed dose to an individual from continuous exposure in the area (Sv)

SF = the shielding factor

and

CD_t = the ratio of the 70-year committed dose at time **t** to that at time zero

Note that the value reported for the population dose is valid only if the cleanup level is in terms of dose commitment.

4.4.3 Dose to Radiation Workers

The radiation exposure to workers performing the decontamination activities is calculated based on the following assumptions:

1) The work is performed over a relatively short period of time.

2) The exposure rate is relatively constant over the decontamination period.

3) The relative radionuclide concentrations correspond to those used to prepare the data file.

With these assumptions, **WD**, the dose to workers in person-Sv, is calculated as

$$WD = H \cdot SF \cdot C \cdot DR/DC \cdot DKR_t \tag{7}$$

where

H = total man-hours involved in decontamination of the area

SF = the shielding factor

C = 70-year committed dose to an individual from continuous exposure in the area (Sv)

DR/DC = the reciprocal of the dose commitment to dose rate conversion factor for the given radionuclide mix at time zero

and

DKR_t = the fraction of the initial dose rate remaining after time **t**.

4.4.4 Number of Cars to be Decontaminated

The number of cars that need to be decontaminated depends on 1) the number of cars per household, 2) whether the accident occurs on a weekday or during the weekend, and 3) the time of day of the accident. Cars that are used in the evacuation are assumed not to require decontamination.

The number of cars per household in the U.S. averages 1.57, although there is significant regional variation. If the population is evacuated, it is assumed that 30 percent of these vehicles remain behind in residential areas, while the remaining 70 percent are used in the evacuation.

The time and day of the accident are used to distribute the cars among residential, commercial and industrial properties. However, if there is an evacuation, the time and day of the accident are assumed not to be important, since it seems likely that noncommercial vehicles located within commercial and industrial areas would first be driven to residential areas, where families would reunite prior to evacuation. In other words nearly all privately owned cars would vacate the commercial and industrial areas.

On the other hand, if the accident occurs and there is insufficient warning and/or no evacuation, then the geographical distribution of noncommercial cars will depend upon the time of day and whether or not the accident occurs on a weekend. The distribution given in Table 4.1 is assumed if there is no evacuation.

Additional details regarding the derivation of the number of cars per household and their distribution over the accident site are reported in Appendix A, Section A.6.4.

4.4.5 Surveying and Monitoring Costs

Several different types of surveying and monitoring activities would take place following a severe radiological accident. Surveying activities, beginning with an aerial survey immediately after the accident, would continue until decontamination has been completed. Monitoring activities continue for several years after decontamination to ensure that radiation remains below some prescribed level. DECON evaluates these activities according to the schedule in Table 4.2 and the costs as given in Table 2.31 in Chapter 2. Since the activities occur over an extended time period, all of the costs are discounted to the time of the accident.

Table 4.1. Distribution of Cars by Land Use, by Accident Time (percent)

Weekday

Hour	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
Resid	92	93	94	95	94	92	84	50	30	30	30	35
Comm	6	5	4	3	3	4	4	35	55	55	55	41
Indus	2	2	2	2	3	4	12	15	15	15	15	14

Hour	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
Resid	30	30	35	45	60	70	77	79	80	80	87	90
Comm	55	55	51	43	32	25	18	16	15	15	9	8
Indus	15	15	14	12	8	5	5	5	5	5	4	2

Weekend

Hour	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
Resid	89	90	91	92	91	90	91	86	81	71	51	51
Comm	9	8	7	6	6	6	5	10	15	25	45	45
Indus	2	2	2	2	3	4	4	4	4	4	4	4

Hour	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
Resid	46	46	51	61	66	76	81	86	86	87	89	89
Comm	50	50	45	35	30	20	15	10	10	10	9	9
Indus	4	4	4	4	4	4	4	4	4	3	2	2

Source: Pacific Northwest Laboratory