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

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

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

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

2.4.4 Agricultural Fields

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

There are a variety of fixatives appropriate for use on soil. Section A.7.1 in Appendix A provides a general discussion of fixatives and their characteristics. For use on agricultural fields, this report assumes

application of Coherex or a similar product. This would be applied using a tank truck with spray application ability.

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

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

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

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

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

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

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

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

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

2.4.5 Orchards

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

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

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

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

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

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

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

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

Operation	Rate (m^2/hr)	Cost (1982 $\$/m^2$)			
		Total	Labor	Equipment	Material
Water	3,541	0.0014	0.0014		
Fixative, aerial application	7,467	0.371	0.019	0.262	0.090
Fixative, ground application to trees and ground	280	0.213	0.027	0.047	0.10
Defoliate	8,331	0.0146	0.0006	0.0015	0.0105
Leach, $FeCl_3$	2,545	0.0338	0.0034	0.0030	0.026
Scrape without removing trees	148	0.658	0.496	0.162	
Plow	8,047	0.0044	0.0906	0.0018	
Remove and replace	98	1.185	0.355	0.595	0.236
Radical prune	340	0.071	0.029	0.042	
Cover with soil, trees removed	549	0.371	0.106	0.265	
Cover with soil, trees not removed	55	1.94	1.38	0.56	
Scrape with trees removed	875	0.31	0.13	0.18	

2.4.6 Vacant Land

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

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

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

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

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

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

2.4.7 Wooded Land

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

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

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

Operation	Rpte (m^2/hr)	Cost (1982 $/m²)			
		Total	Labor	Equipment	Material
Fixative, aerial	5,600	0.49	0.025	0.350	0.120
Defoliate	5,554	0.0220	0.0009	0.0023	0.0158
Clear	266	0.802	0.469	0.33	
Grub and scrapc	656	0.59	0.23	0.36	
Hand scrape	4	4.61	4.36	0.25	
Covcr, clcarcd land	549	0.371	0.106	0.265	
Cover by hand	6	3.24	2.95	0.29	

2.4.8 Exterior Walls

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.4.9 Interior Floor and Walls

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.4.10 Automobiles

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.4.11 Hauling

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

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

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

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

2.5 DECONTAMINATION EFFICIENCIES FOR VARIOUS SURFACES

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

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

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

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

2.5.1 Cost and Efficiencies of Decontamination Methods

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

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

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

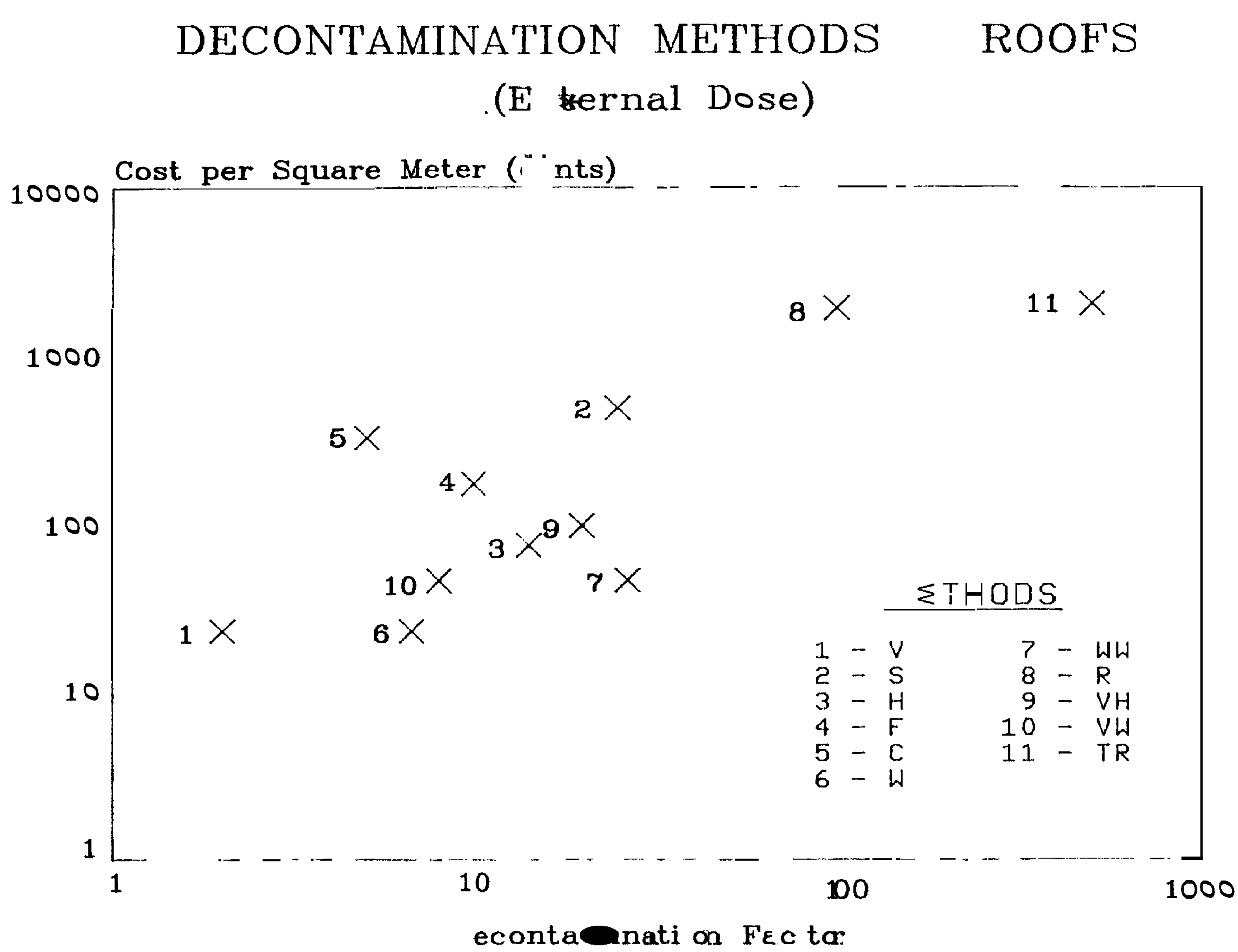

FIGURE Z 5 1 Decontamination Co ts fo Roofs, by Metho ad D≤cotaamination Factor

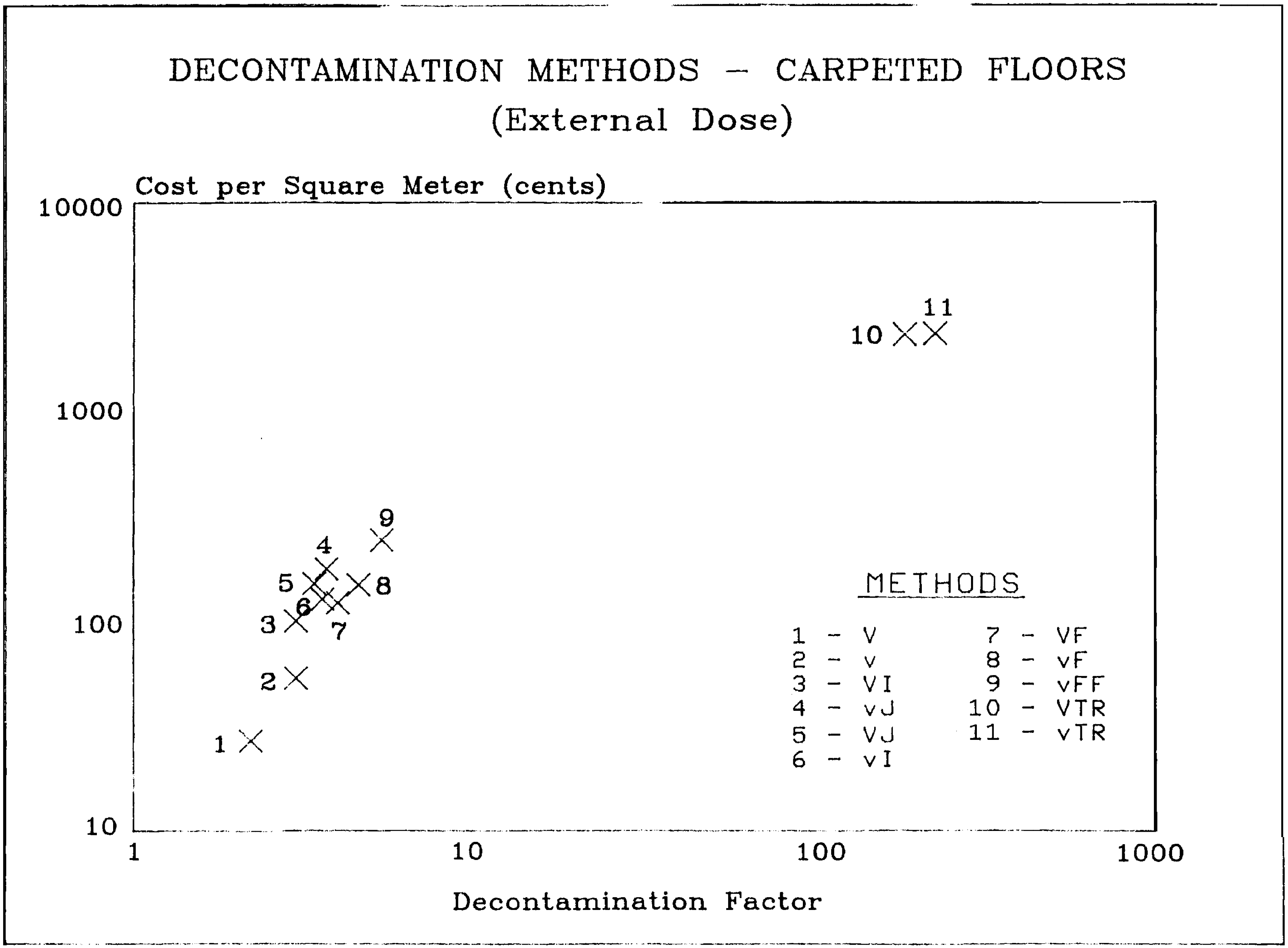

FIGURE 2.5.2 Decontamination Costs for Carpeted loors, by Method and Decontamination Factor

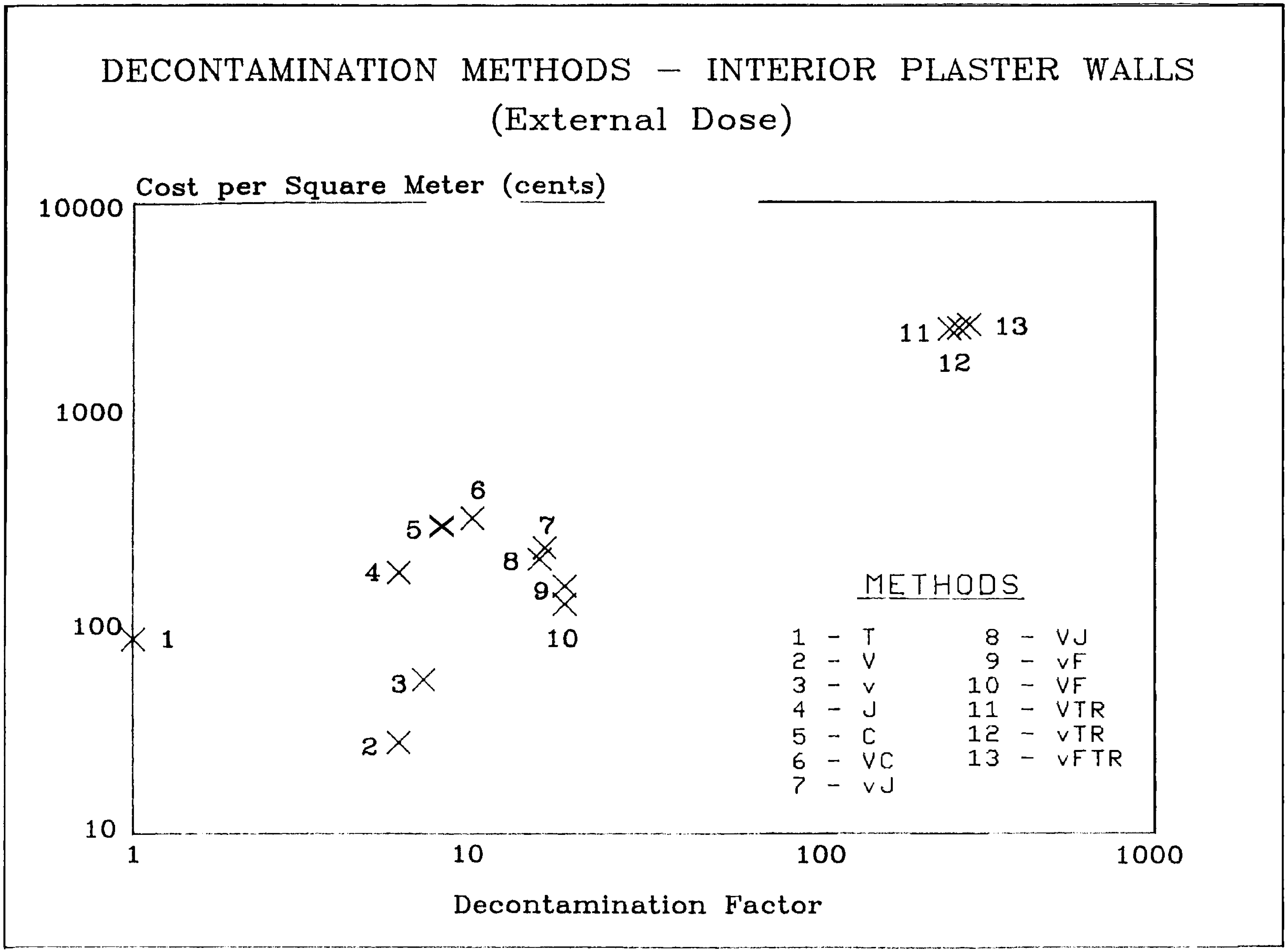

FIGURE 2.5.3. Decontamination Costs for Interior Plaster Walls, by Method and Decontamination Factor

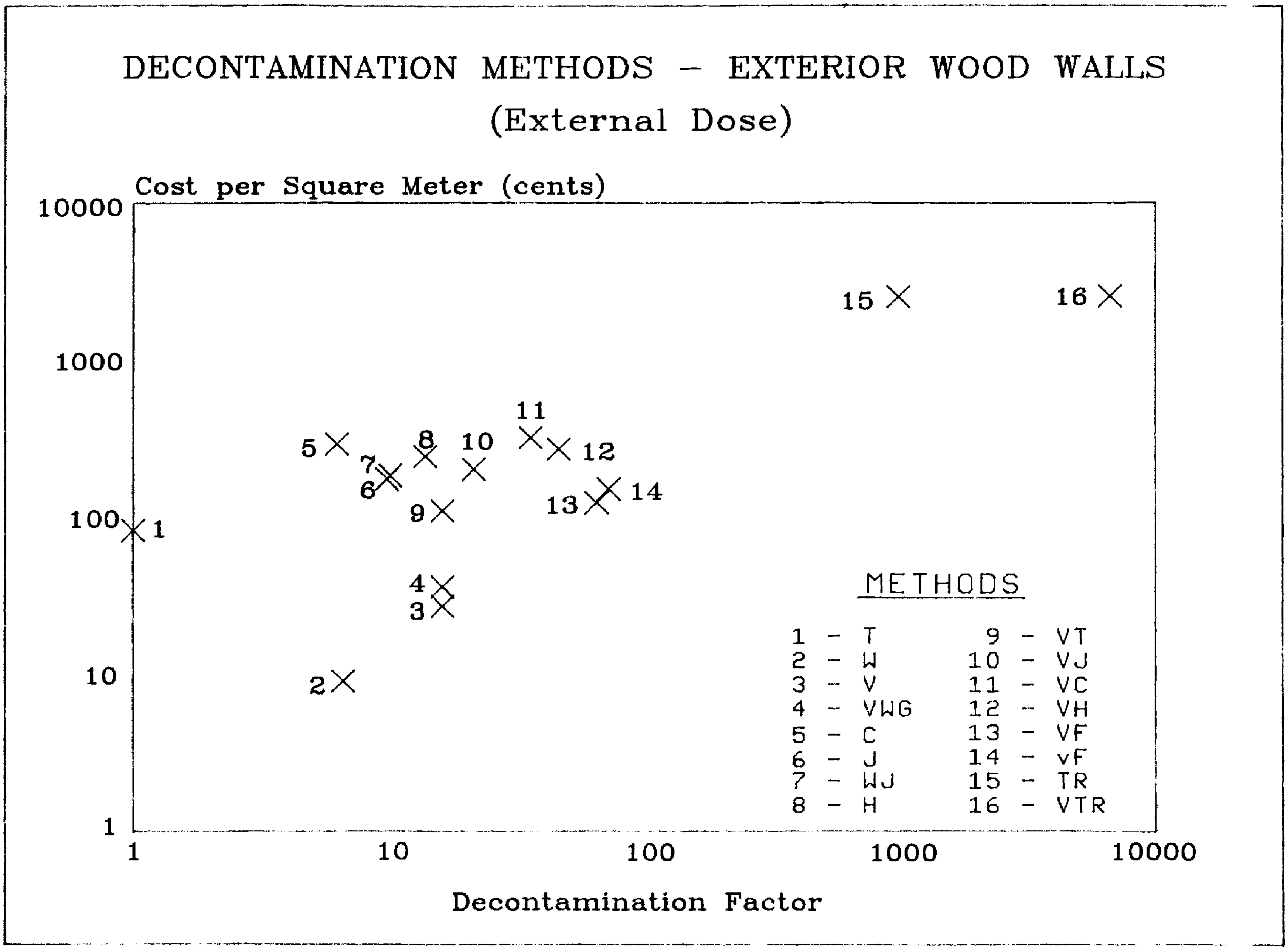

FIGURE 2.5.4. Decontamination Costs for Exterior Wood Walls, by Method and Decontamination Factor

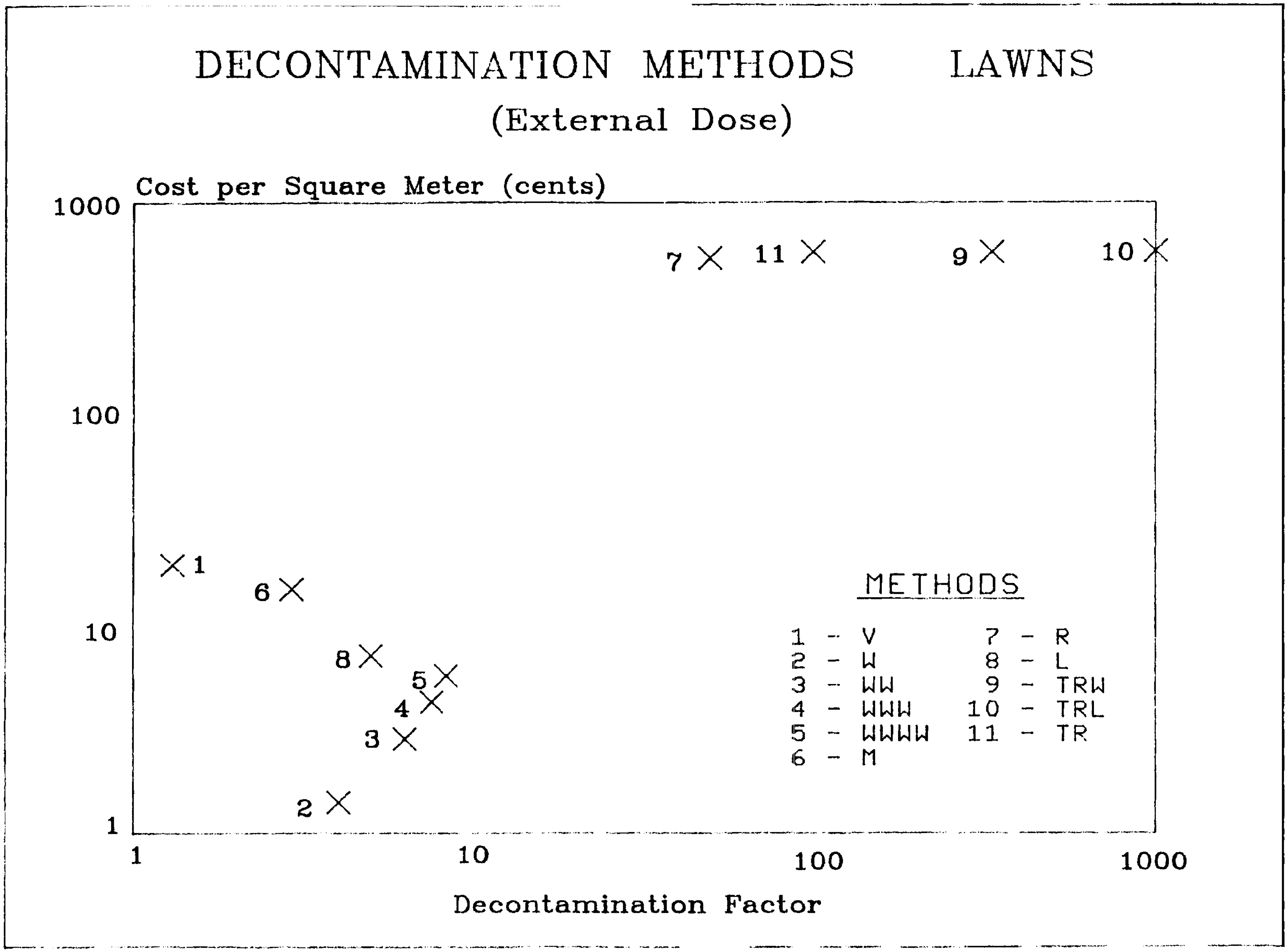

FIGURE 2.5.5 Decontamination Costs for Lawns, by Method and Decontamination Factor

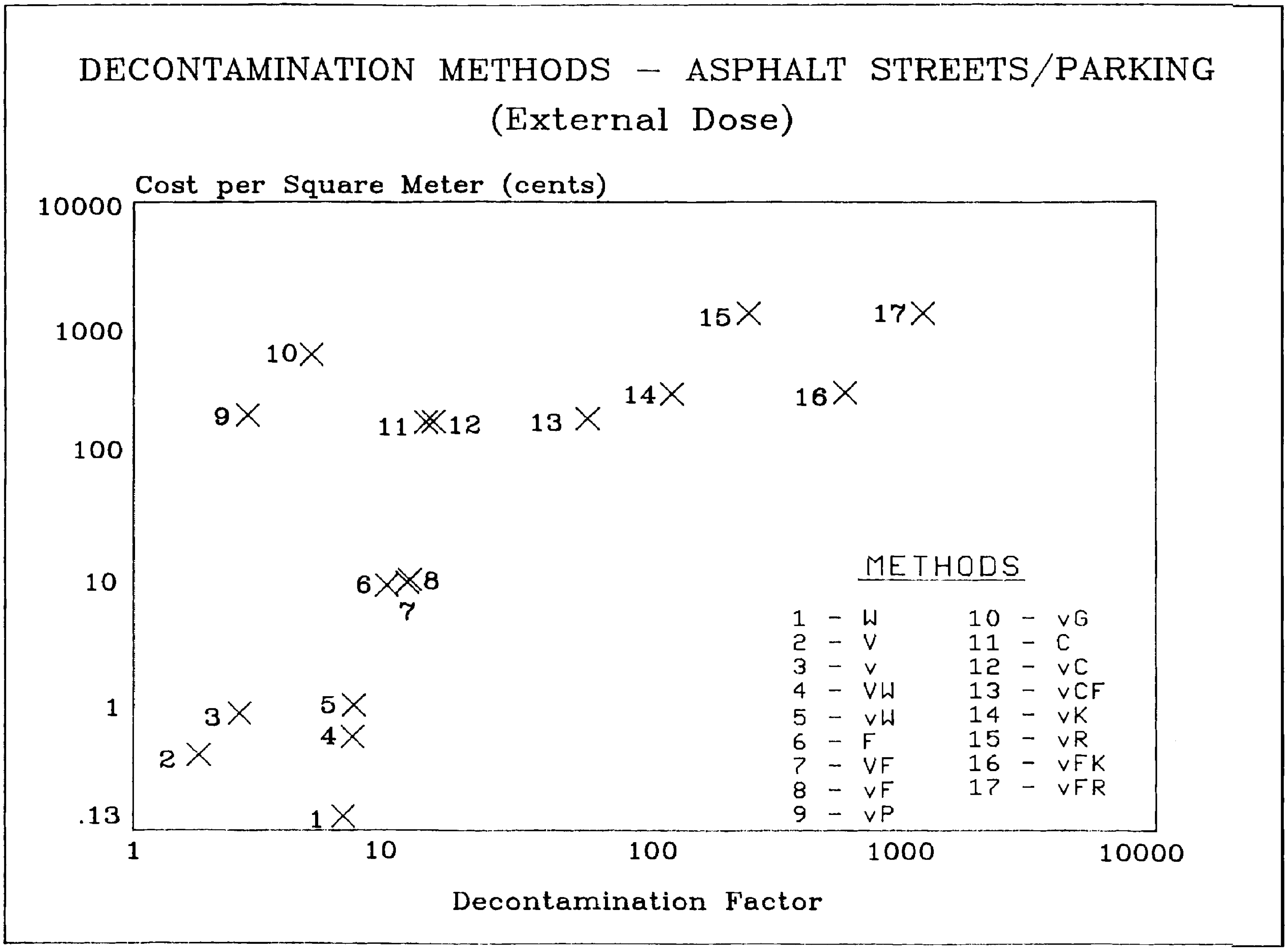

FIGURE 2.5.6. Decontamination Costs for Asphalt Streets/Parking, by Method and Decontamination Factor

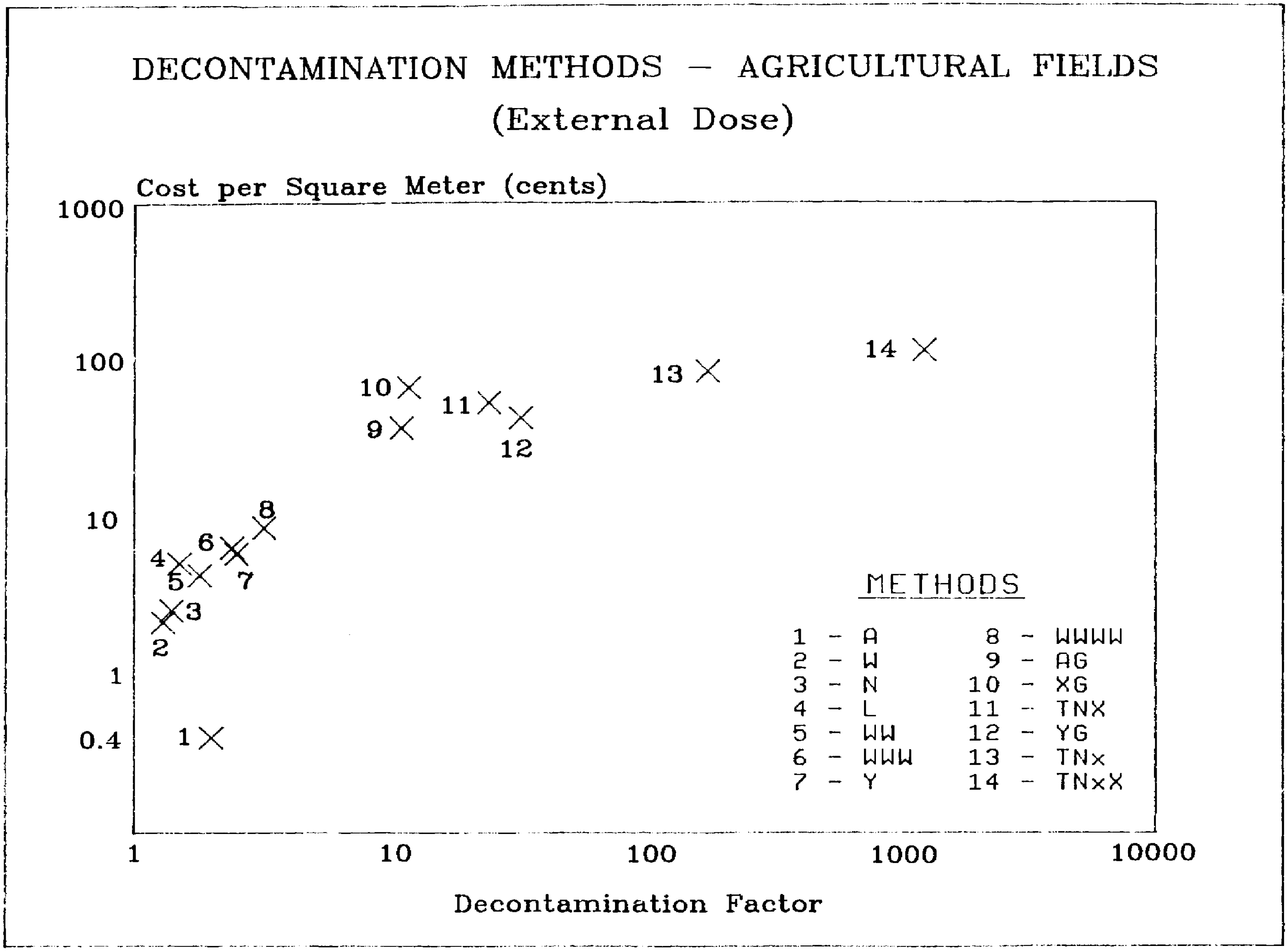

FIGURE 2.5.7. Decontamination Costs for Agricultural Fields, by Method and Decontamination Factor

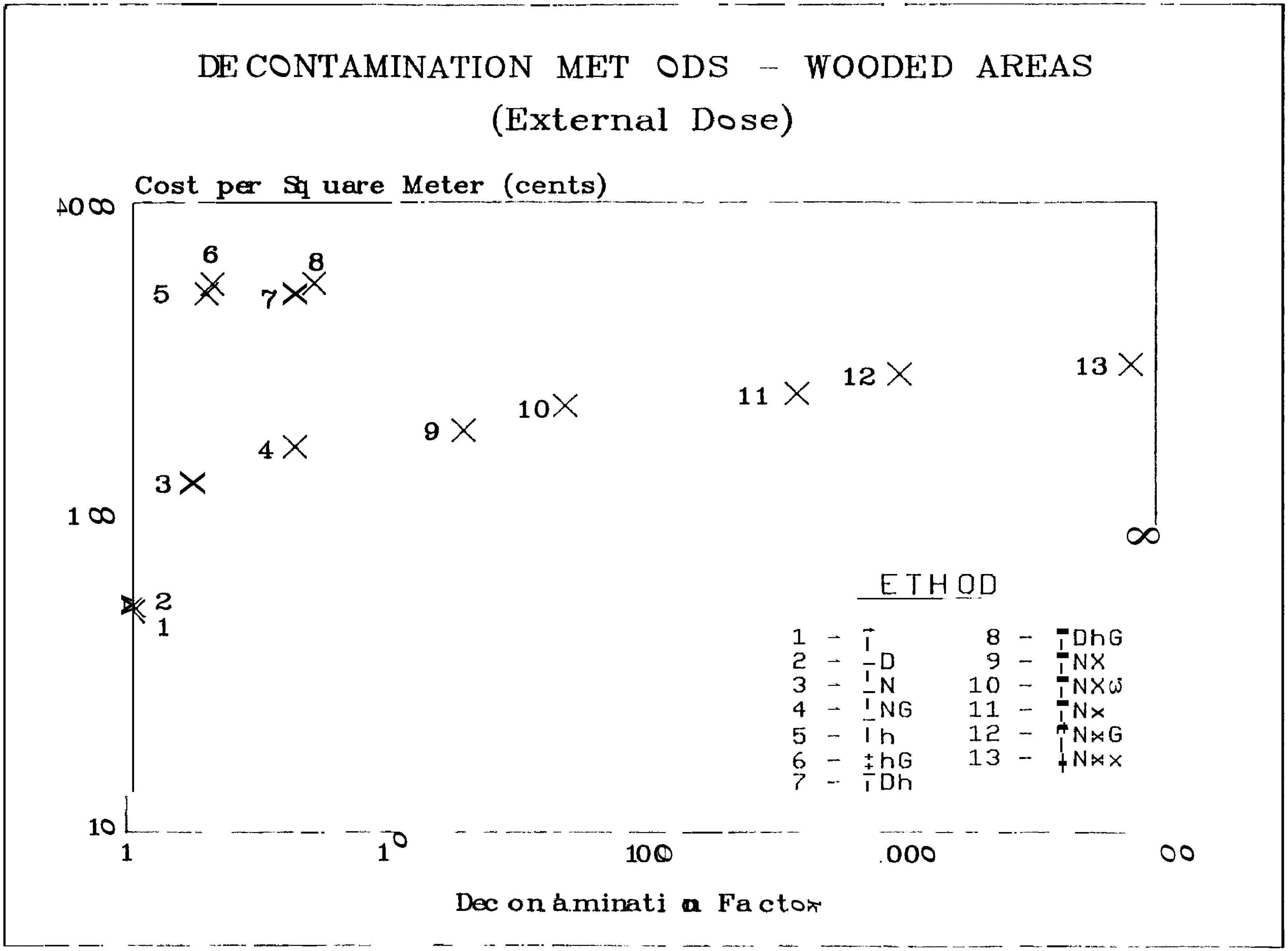

FIGURE 2 58. econtamin ion Costs f Wooded A eas, by Method and Decontamination Fac or

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

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

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

3.0 THE SITE DATA BASE

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

3.1 SELECTION OF THE GRID

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

3.1.1 Rectangular Grid

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

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

In the absence of population counts for each grid element, one could simply assume that the population within each political subdivision is uniformly distributed geographically. This approach, however, could be improved through the use of topographical maps of the U.S. Geological Survey. The 7-1/2 minute

series maps show individual house and business establishments. Unfortunately, small business establishments are not distinguishable from residences, and large multi-family establishments are indistinguishable from other large buildings. Nevertheless, knowing where the developed property is can be an aid in estimating the population within each grid element.

3.1.2 Radial Grid

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

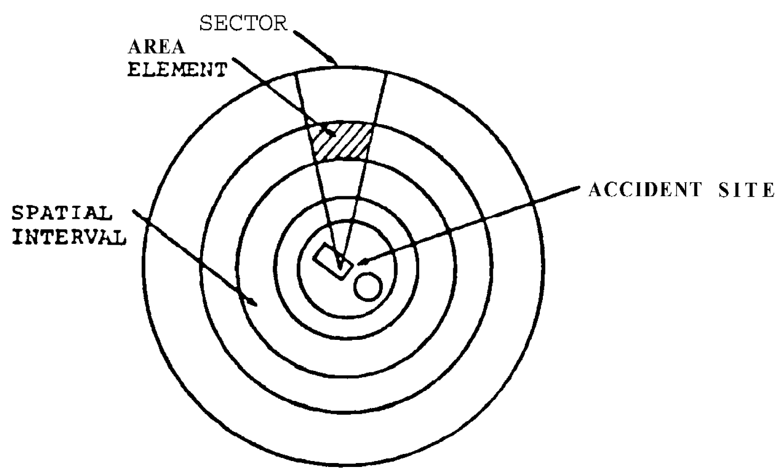

FIGURE 3.1. Typical Radial Grid Geometry

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

To make the radial grid a more attractive option, the PNL-developed software program mentioned in the previous section is directly applicable. This program uses actual population counts for the grid elements to increase the accuracy of imputing land uses and property values to each grid element. The

population counts for this technique have been developed for the NRC by Oak Ridge National Laboratory and are available for the areas surrounding all existing reactor sites.

3.1.3 Irregular Grid Based on Political Subdivision Boundaries

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

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

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

3.2 CONTENTS OF THE SITE DATABASE

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

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

3.2.1 Contamination Level

The site database must provide DECON with information on the severity of the contamination of exterior, horizontal surfaces. The information can be supplied in units of dose, dose commitment, ground concentration or other comparable unit, as long as the cleanup criterion is also specified in the same unit. DECON forms a ratio between the contamination measure and the cleanup criterion to obtain a target decontamination factor. The target decontamination factor is the factor by which contamination must be removed from the

surface in order to meet the cleanup criterion. For example, if the ground concentration within a grid element gives an external 70-year dose commitment of 250 rem, a cleanup criterion of 10 rem results in a target decontamination factor of 250 ÷ 10 = 25. To meet a cleanup standard of 10 rem, 25 parts of contaminant must be removed from the contaminated surface for every one part that is allowed to remain on it.

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

3.2.2 Type of Property Contaminated

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

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

TABLE 3.1. Land Uses Currently Implemented in DECON

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

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

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

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

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

3.2.3 Value of the Contaminated Property

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

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

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

3.3 SOFTWARE TOOLS FOR PREPARING THE SITE DATABASE

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

- determining dose at any downwind location on or off the plume centerline

- generating the grid pattern for a radial grid, given the accident parameters and the distance intervals

- transforming land use areas into areas of surfaces, by surface categories

- using information based on political subdivisions for imputing information to grid elements

- using a stochastic process to assign property values when alternative information sources are inadequate.

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

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

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

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

4.1 METHODS USED IN CRAC2

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

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

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

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

---

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

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

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

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

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

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

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

view of the important role that consequence analysis plays in formulating safety-related policies.

4.2 INFORMATION PRODUCED BY DECON

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

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

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

4.2.1 Maximizing Property Values through Site-Restoration Actions

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

4.2.1.1 Residual Contamination

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

---

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

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

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

$$V_o = kV_b$$

The magnitude of k should depend both on the type of property and the level of residual contamination.

4.2.1.2 Deterioration and Obsolescence

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

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

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

In this formula df is the annual depreciation factor due to deterioration and obsolescence.

4.2.1.3 Loss of Use of Property

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

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

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

4.2.1.4 Decontamination Costs

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

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

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

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

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

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

4.2.2 Algorithm to Maximize Property Values

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

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

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

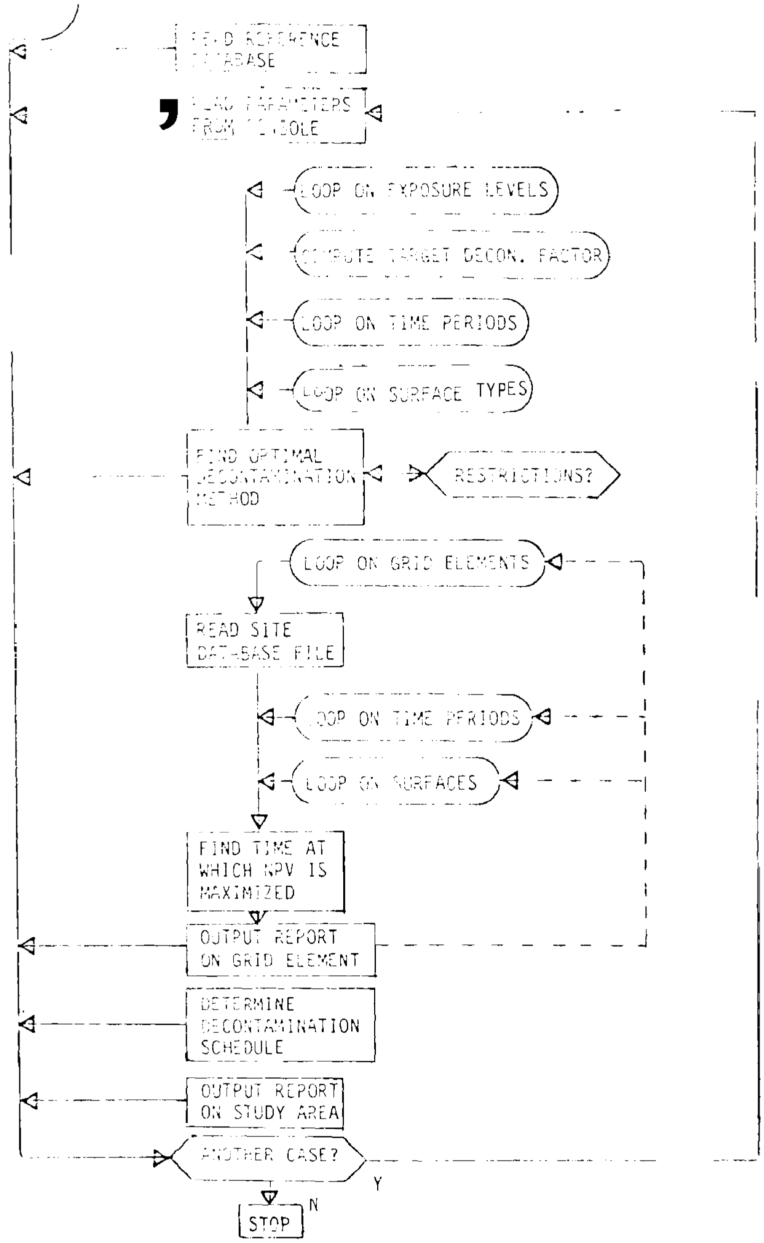

FIGURE 4.1. Primary Logic of DECON

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

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

4.2.3 Effects on Property Values When No Decontamination is Required

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

4.2.4 Property that Cannot Be Decontaminated

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

---

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

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

4.2.5 Properties with Negative Net Present Values

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

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

4.2.6 Contamination Model

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

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

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

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

4.3. SPECIAL FEATURES

DECON has been designed with many special features to facilitiate its use in site restoration analysis. To assist the user, DECON is almost entirely

menu driven. Several different output formats are available through the report writer. Detailed information by surface can be produced for individual grid elements, or summary data only can be selected. Summaries are for the entire study area and, optionally, for grid elements. Other special features are described below.

4.3.1 Subarea Analysis

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

4.3.2 Pre-Rain Analysis

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

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

4.3.3 Restrictions

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

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

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

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

4.3.4 Required Methods

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

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

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

4.3.5 Variation in Exposure Levels

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

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

4.3.6 User-Selectable Parameter Values

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

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

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

worker productivity; and 3) increase the costs of labor and capital because operations are being performed on a small scale.

4.3.7 Future Capabilities

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

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

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

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

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

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

Number of Autos. DECON currently produces information on the decontamination of automobiles, including exteriors, interiors, tires, and drive train. The results, however, are reported for only one "unit" of automobiles, where the number of automobiles per unit is equal to the scale factor used in presenting the results. Because automobiles would almost certainly be the principal means for evacuating an area, it is not clear how many would remain

within the contamination zone. Research on evacuations from natural disasters, such as hurricanes, could provide some useful information.

4.4 FLEXIBILITY OF DECON

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

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

5.0 A CASE STUDY USING DECON

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

5.1 PREPARATION FOR CONDUCTING THE CASE STUDY

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

5.1.1 Purpose of the Models

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

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

5.1.2 Running the Models

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TABLE 5.3. Representative Land Use Categories

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

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

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

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

TABLE 5.5. Data for Counties in the Accident Area

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

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

TABLE 5.6. Distribution of Households Within Accident Area

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

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

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

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

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

This file is read directly by DECON.

5.2 RESULTS

The results of the site restoration analysis are presented in this section. DECON is used to explore various strategies aimed at minimizing the consequences of this simulated accident. First, DECON was run for the entire contaminated area. This run represents the base case and is reported in Section 5.2.1. A variety of different assumptions was then made and the results compared with those from the base case. In Section 5.2.2, some results are presented that show how the decontaniination schedule is developed. In Section 5.2.3, a detailed printout for a single grid element is examined, and the information provided by this printout is explained. In Section 5.2.4 an

analysis is conducted to illustrate the restricting of methods using water, and Section 5.2.5 demonstrates an application in which water is pre-specified as the method to be used on agricultural fields. Section 5.2.6 demonstrates how the exposure factors can be varied both to reduce expected dose and to reduce decontamination costs and property losses. In Section 5.2.7 DECON is used to produce information showing the tradeoff between cleanup standards and decontamination costs. Conclusions are given in Section 5.2.8.

5.2.1 Base Case

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

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

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

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

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

5.2.2 Decontamina :hedu

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

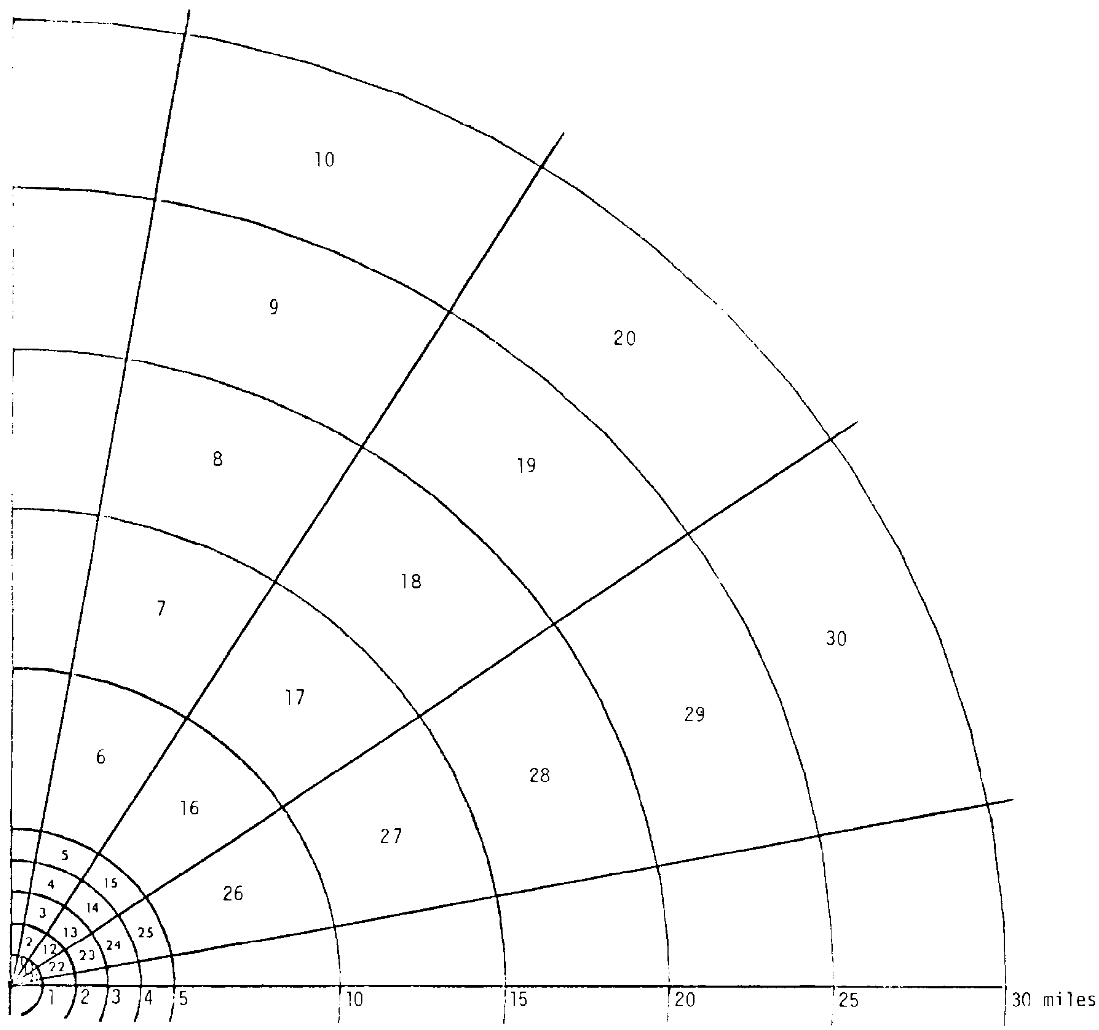

FIGURE 5.1 Radial Grid for Case Study

TABLE 5.7 Decontamination Results for the Base Case

SUMMARY RESULTS FOR EXPOSURE AREA 1 TO EXPOSURE AREA 14

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

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

TOTAL FACTOR INPUT REQUIREMENTS
(MAN/EQUIPMENT HOURS)

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

TABLE 5.7 (cont.)

TOTAL AREA DECONTAMINATED, BY SURFACE AND METHOD

SURFACE TYPE	METHOD	AREA (SQ. METERS)
AGRICULTURAL FIELDS	X	25655.
AGRICULTURAL FIELDS	A	18230.
AGRICULTURAL FIELDS	AG	20579.
VACANT LAND	W	8090.
VACANT LAND	A	25343.
WOODED LAND	TNX	10820.
WOODED LAND	TNx	8669.
WOODED LAND	TDh	965.
WOODED LLAND	TX	9093.
LINQLEUH FLOORS	V	12608.
WOOD FLOORS	V	9582.
CARPETED FLOORS	V	20178.
CARPETED FLOORS	v	117.
CARPETED FLOORS	VF	117.
CARPETED FLOORS	vF	1929.
CARPETED FLOORS	vFF	120.
CONCRETE FLOORS	V	8748.
CONCRETE FLOORS	v	1885.
ASPHALT STRTSIPRKNG	W	14686.
ASPHALT STRTS/PRKNG	F	2037.
CNCRETE STRTS/PRKNG	W	12608.
CNCRETE STRTS/PRKNG	F	1768.
ROOFS	V	55001.
ROOFS	W	28529.
ROOF5	WW	3530.
ROOFS	VW	242.
LAWNS	W	117870.
LAWNS	WW	71250.
LAWNS	WWWW	207.
LAWNS	R	5455.
OTHR PAVED ASPHALT	W	2695.
OTHR PAVED ASPHALT	F	78.
OTHR PAVED CNCRETE	W	10795.
OTHR PAVED CNCRETE	F	319.

TABLE 5.8 Decontamination Schedule for Grid Elements 12 Through 16

SUMMARY RESULTS FOR GRID ELEMENT 12

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

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING	1.0000
RADIATION LIMIT FOR ORGAN 1 IS	10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........	30
OPTIMAL TIME TO DECONTAMINATE IS IN YEAR......	13 ←
ANNUAL DEPRECIATION FACTOR IS................	.10
DISCOUNT FACTOR IS........................	.10
DISCOUNT FOR RESIDUAL CONTAMINATION IS	.10
TOTAL DECONTAMINATION COSTS ARE............ $	4377.
TOTAL AREA DECONTAMINATED IS.	1674.0 SQUARE METERS
AVERAGE DECONTAMINATION COSTS/M**2 ARE ...... $	2.61
AREA REQUIRING NO DECONTAMINATION IS.........	353.4 SQUARE METERS
AREA THAT COULD NOT BE DECONTAMINATED IS.....	.0 SQUARE METERS
PRE-ACCIDENT PROPERTY VALUE IS .... $	26449.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $	23004.
NET PRESENT VALUE OF PROPERTY IS .... $	485.
TOTAL REDUCTION IN PROPERTY VALUE IS .... $	25964.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS	24.715 MAN-REM.
SIZE OF RESIDENT POPULATION	166. PERSONS.

SUMMARY RESULTS FOR GRID ELEMENT 13

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

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

TABLE 5.8 (cont.)

SUMMARY RESULTS FOR GRID ELEMENT 14

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

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING	1.0000.
RADIATION LIMIT FOR ORGAN 1 IS	10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........	30
OPTIMAL TIME TO DECONTAMINATE IS IN YELAR......	4 ←
ANNUAL DEPRECIATION FACTOR IS................	.1.0
DTSCOLJNT FACTOR IS..........................	.10
DISCOUNT FOR RESIDUAL CONTAMINATION IS........	.10
TOTAL DECONTAMINATION COSTS ARE............. $	9573.
TOTAL AREA DECONTAMINATED IS................	3896.0 SQUARE METERS
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $	2 46
AREA REQLJIRTNG NO DECON'I'AMINATION IS.........	780.7 SQUARE METERS
AREA THAT COULD NOT BE DECONTAMINATED IS.....	.0 SQUARE METERS
PRE-ACCIDENT PROPERTY VALUE IS .... $	61738.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $	55564.
NET PRESENT VALUE OF PROPERTY IS .... $	18361.
TOTAL FZEDLJCTTON IN PROPERTY VALUE IS .... $	43376.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS	44.291 MAN-REM.
SIZE OF RESIDENT POPULATION	333. PERSONS.

SUMMARY RESULTS FOR GRID ELEMENT 15

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

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING	1.0000.
RADIATION LIMIT FOR ORGAN 1 IS	10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........	30
OPTIMAL TIME: TO DECONTAMINATE IS XN YEAR......	3 ←
ANNUAL DEPRECIATION FACTOR IS................	10
DISCOUNT FACTOR IS...........................	.10
DISCOUNT FOR RESIDUAL CONTAMINATION IS........	1.0
TOTAL DECONTAMINATION COSTS ARE............. $	10621.
TOTAL AREA DECONTAMINATED IS................	4994.0 SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $	2.13
AREA REQUIRING NO DECONTAMINATION IS.........	958.3 SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....	.0 SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS .... $	79347.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $	71412.
NET PRESENT VALUE OF PROPERTY IS .... $	31133.
TOTAL REDUCTION IN PROPERTY VALUE IS .... $	48214.
WHOLE BODY EXT. DOSE TO RAO. WORKERS IS	44.517 MAN-REM.
SIZE OF RESIDENT POPULATION	371.. PERSONS.

TABLE 5.8 (cont.)

```
SUMM...      ...S FOR GRID ELEMENT    1?

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

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING      1.0000.
RADIATION LIMIT FOR ORGAN 1 IS ...............         10.00
NUMBER OF TIME PERIODS CONSIDERED IS..........            30
OPTIMAL TIME TO DECONTAMINATE IS IN YEAR......             1 <--
ANNUAL DEPRECIATION FACTOR IS.................           .10
DISCOUNT FACTOR IS............................           .10
DISCOUNT FOR RESIDUAL CCINTAMINATION IS........          .10
TOTAL DECONTAMINATION COSTS ARE.............. $      109291.
TOTAL AREA DECONTAMINATED IS..................      43423.0 SQUARE METERS
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $         2.92
AREA REQUIRING NO DECONTAMINATION IS.........       12725.7 SQUARE METERS
AREA THAT COULD NOT BE DECONTAMINATED IS.....            .0 SQUARE METERS
PRE-ACCIDENT PROPERTY VALUE IS .............. $     661227.
POST-DECONTAMINATION PROPERTY VALUE IS ...... $     595104.
NET PRESENT VALUE OF PROPERTY IS ............ $     387584.
TOTAL REDUCTION IN PROPERTY VALUE IS ........ $     273642.
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS ......      578.276 MAN-REM.
SIZE OF RESIDENT POPULATION ..................        9043. PERSONS.
```

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

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

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

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

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

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

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

5.2.3 Micro-Analysis of a Grid Element

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

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

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

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

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

TABLE 5.9 Micro-Analysis of Grid Element 15

DETAILED SURFACE RESULTS FOR GRID ELEMENT 15

*** RAIN ***

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

SURFACE	AREA	DOSE	ATDF	METH	DF	COST/M**2	TOT. COST	RATE::
AGRICULTURAL FIELDS	2036	'76.96	7.7	AC	11.1	1.2120	2467.87	549
VACANT LAND	796	76 96	7.7	A	20.0	.0280	22.29	1770
WOODED LAND	85'7	7L.96	7.7	TNx	9.3	8.8260	7571.97	26A
EXTERIOR WOOD WALLS	102	7.70	.8	----				
EXTER'R BRICK WALLS	215	7.70	.8	----	....	....	....	.....
LINOLEUM FLOORS	1'74	38.48	3.8	V	20.0	.2700	47.11	69
WOOD FLOORS	25	30.48	3.8	V	6.7	.2700	6.90	69
CARPETED FLOORS	1.1.7	38.48	3.8	VF	4.0	1.2300	144.72	40
CONCRETE FLOORS	1.51	38.48	3.8	v	4.7	.5400	81.86	69
INT'R WOOD/PL WALLS	526	3.85	.4	----	....	....	....	.....
TNT'I? CNCRETE WALLS	113	3.85	4	----	....	....	....	.....
ASPHALT STRTS/PRKNG	202	76 96	7.7	F	10.0	.0911	18.40	17186
CNCRETE STRTS/PRKNG	175	76.96	7.7	F	10.0	.0911	15.97	17186
ROOFS	242	76.96	7.7	VW	8.0	.4600	111.45	81
LAWNS	207	76.96	7.7	WWW	8.4	.0560	11.60	1302
AUTO EXTERIORS	1	76.96	7.7	TWW	14.3	60.0000	60.00	1
AUTO INTERIORS	1	76.96	7.7	v	9.5	10.0000	10.00	3
AUTO TIRES	1	76.96	7.7	S	8.3	12.7100	12.71	8
AUTO ENG/DRV TRAIN	1	76.96	7.7	E	10.0	36.9000	36.90	1
OTHR PAVED ASPHALT	2	76.96	7.7	F	10.0	.0995	.29	8593
OTHR PAWED CNCRETE	11	76.96	7.7	F	10.0	.0995	1.17	8593

NOTES:

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

TOTAL FACTOR INPUT REQUIREMENTS
(MAN/EQUIPMENT HOURS)

DRIVER, HEAVY TRUCK	10.41
OPERATOR, I F EQUIPMENT	27.21
OPERATOR, LIGHT EQUIPMENT	.13
OPERATOR, FARM EQUIPMENT	.69
BUILDING LABORER	18.63
COMMON LABORER	1.67
CLEANING WORKER	12.20
FOREMAN	5.84
PILOT	.17
FLIGHT CREWMAN	.17
AIR GROUND CREWMAN	.34
SPRAY OPERATOR	2.94
FRONT END LOADER	10.98
BULLDOZER	3.71
AIRPLANE	.17
TRACTOR W/PLOW	.69
CHIPPING MACHINE	3.23
HYDRAULIC EXCAVATOR	3.24
VACUUM, HAND	11.37
PAINT SPRAY EQUIPMENT	2.94
VACUUMIZED STREET SWEEPER	.02
SANDBLAST EQUIPMENT	.13
TOW TRUCK	1.00
GRADER	2.62
VEHICLE WASHING EQUIPMENT	.50
DUMP TRUCK	9 41
SMALL TANK-SPRAY TRUCK	.02