5.6 EVALUATING OTHER CLEANUP STRATEGIES

In this section we show how DECON can be used to evaluate many different site restoration strategies. We will examine the effect on decontamination costs when: 1) some outside surfaces are vacuumed before they get rained on; 2) the radiological waste generated in the cleanup is transported to an off-site, licensed facility for disposal; 3) wooded areas, which are very costly to decontaminate, are treated only to prevent resuspension of the contaminants and are then closed off to public access; 4) the use of water to treat outside surfaces is prohibited because of the risk to underground water supplies; and 5) different cleanup levels are applied to different types of surfaces, depending upon the health risk posed by each type of surface.

5.6.1 Pre-Rain Cleanup

If loose contaminated particles can be vacuumed up before precipitation bonds them to exterior surfaces, the decontamination effort and therefore decontamination costs can be reduced. This strategy was evaluated by running the base case, but with the Quick-Vac option selected. The results show that this strategy reduces the decontamination costs for real property from $710 million in the base case to $625 million, for a reduction of 12%.

5.6.2 Off-Site Waste Disposal

This analysis examines the effects on site restoration costs if the wastes are hauled to an off-site licensed disposal facility that accepts low-level radiological waste. With on-site disposal we assumed an average hauling distance of 24 km from the location where the waste was generated, and a burial cost of $11.34 per cubic meter. For off-site disposal, the assumed one-way hauling distance is 500 km, and the assumed disposal cost is $100 per cubic meter. In the base case, 13.8 million cu meters of waste were disposed on-site at a cost of $159 million. With off-site burial, the volume of waste to be disposed of falls to 9.0 million cu meters, with off-site disposal costs rising to $900 million. The reason for the reduced waste volume is that DECON chooses among the decontamination methods and selects the optimal time to decontaminate each grid element so as to minimize overall losses. With the more costly off-site disposal, there is some substitution of cleanup methods that generate less waste. This is accomplished partly by allowing the activity to decay several years before beginning restoration.

Since, under this scenario, the waste must now be transported to a waste disposal facility 500 km away, transportation costs add significantly to the total decontamination costs. Compared with a decontamination cost of $710 million in the base case, real property decontamination costs now soar to $2.8 billion.

SUMMARY RESULTS FOR GRID ELEMENT 1 TO GRID ELEMENT 98

*** EXTERNAL PATHWAY ***

CLEANUP LEVEL	2.50E-01	SIEVERTS
NUMBER OF TIME PERIODS CONSIDERED	3.00E+01	
TOTAL SURVEYING AND MONITORING COSTS .... $	1.45E+08	
NPV DECONTAMINATION COSTS FOR ALL PROPERTY ...$	9.43E+08	
REAL PROPERTY		
DECONTAMINATION COSTS .... $	7.10E+08	
SURFACE AREA THAT CAN BE DECONTAMINATED	3.36E+04	HECTARES
AVERAGE DECONTAMINATION COSTS	2.11E+00	$/m**2
SURFACE AREA REQUIRING NO DECONTAMINATION ...	6.88E+04	HECTARES
SURFACE AREA NOT ABLE TO DECONTAMINATE	0.00E+00	HECTARES
BUILDING CONTENTS		
DECONTAMINATION COSTS .... $	6.61E+08	
NUMBER ABLE TO DECONTAMINATE	4.55E+05	UNITS
AVERAGE DECON COST PER UNIT .... $	1.45E+03	
NUMBER REQUIRING NO DECONTAMINATION	3.98E+06	UNITS
NUMBER UNABLE TO DECONTAMINATE	0.00E+00	UNITS
AUTOMOBILES		
DECONTAMINATION COSTS .... $	4.75E+07	
NUMBER ABLE TO DECONTAMINATE	1.14E+05	
AVERAGE DECON COST PER AUTOMOBILE ....$	4.17E+02	
NUMBER REQUIRING NO DECONTAMINATION	1.86E+05	
NUMBER UNABLE TO DECONTAMINATE	0.00E+00	
STUDY AREA		
NUMBER OF GRID ELEMENTS	1.60E+01	
SIZE OF THIS AREA	4.90E+04	HECTARES
SIZE OF RESIDENT POPULATION	5.10E+05	PERSONS
LATENT CANCER FATALITIES FROM POST-DECON DOSE	2.11E+03	PERSONS
VALUE OF REAL PROPERTY, PRE-ACCIDENT ...... $	3.24E+10	
VALUE OF PERSONAL PROPERTY, PRE-ACCIDENT .. $	8.67E+09	
VALUE OF ALL PROPERTY, PRE-ACCIDENT .... $	4.10E+10	
DECONTAMINATION ZONE		
NUMBER OF GRID ELEMENTS	9.00E+00	
SIZE OF THIS AREA	2.34E+04	HECTARES
SIZE OF RESIDENT POPULATION	1.41E+05	PERSONS
VOLUME OF RADIOLOGICAL WASTE	1.38E+07	CUBIC METERS
COSTS FOR BURIAL OF RADIOLOGICAL WASTE .... $	1.59E+08	
EFFECTIVE DOSE EQUIVALENT TO RADWORKERS	3.78E+02	PERSON-SIEVERTS
EFF. DOSE EQUIV. TO POP. IF NOT RELOCATED ...	5.09E+04	PERSON-SIEVERTS
LATENT CANCER FATALITIES FROM POST-DECON DOSE	7.07E+02	PERSONS

Figure 5.14. Summary Results for the Base Case

*** EFFECTS ON REAL PROPERTY, WITH	FULL DECON	BUY-OUTS
VALUE OF REAL PROPERTY, PRE-ACCIDENT	$ 8.78E+09	
NET PRESENT VALUE OF REAL PROPERTY	$ 5.97E+09	5.97E+09
NET PRESENT VALUE LOSSES, REAL PROPERTY ...	$ 2.81E+09	2.81E+09
- RESIDUAL CONTAMINATION LOSSES	$ --------	8.93E+08
- DETERIORATION LOSSES	$ --------	3.94E+08
- LOSS FROM DEFERRED USE	$ --------	7.25E+08
*** EFFECTS ON PERSONAL PROPERTY, WITH	FULL DECON	
VALUE OF PERSONAL PROPERTY, PRE-ACCIDENT ..	$ 3.61E+09	
NET PRESENT VALUE OF PERSONAL PROPERTY	$ 3.01E+09	
*** TOTAL PROPERTY EFFECTS, WITH	FULL DECON	BUY-OUTS
VALUE OF ALL PROPERTY, PRE-ACCIDENT	$ 1.24E+10	
NET PRESENT VALUE OF ALL PROPERTY	$ 8.98E+09	8.98E+09
NET PRESENT VALUE LOSSES, ALL PROPERTY	$ 3.42E+09	3.41E+09
TOTAL POTENTIAL SAVINGS FROM BUY-OUT OF REAL PROPERTY		
- AT PRE-ACCIDENT PROPERTY VALUES	$ --------	0.00E+00
- AT NET PRESENT VALUE OF PROPERTY	$ --------	2.53E+06

Figure 5.14. Summary Results for the Base Case (Continued)

5.6.3 Restricting Access to Wooded Areas

Another site restoration strategy addresses the cleanup of wooded areas. Since the presence of mature trees makes it impractical to use large, efficient equipment in the cleanup effort, restoring wooded areas is especially costly. At the Indian Point accident site, wooded areas occupy 7400 ha within the decontamination zone, or about 15 percent of the total land area. However, decontaminating them to a level of 0.25 Sv accounts for over 64 percent of the total costs to decontaminate real property. One approach for reducing these costs is simply to apply a fixative to the contaminated wooded areas to prevent resuspension of the contaminants, and then to restrict access to the area. While this strategy has little or no effect on expected fatalities, it reduces decontamination costs of real property from $710 million in the base case to just $292 million. The disadvantage with this approach is that it removes these wooded areas from public use.

While the drop in decontamination costs is large, the total accident losses drop only 11%--from $3.42 billion to $3.04 billion. Other property-related losses--such as from residual contamination ($893 million) and deferred use ($725 million)--overwhelm the decontamination costs[2].

[2]In these analyses, we have assumed that at least one year must pass before contaminated property can be returned to use. If this period can be significantly shortened, large reductions in the property-related losses are achievable.

5.6.4 Restricting the Use of Water on Outside Surfaces

In this strategy, we assume that applying water to exterior surfaces poses a potential hazard to underground water supplies. We therefore specify that no operations using water (W and L) would be permitted. When these restrictions are applied, decontamination costs for real property increase to $987 million, or by 39%.

5.6.5 Applying Different Cleanup Criteria to Different Surface Types

In this strategy, we apply different cleanup criteria to different surfaces. The basis for this approach is that the health risk posed by a contaminated surface depends upon its proximity to people and the time of exposure. If we concentrate our resources on decontaminating surfaces that pose relatively high risks, then we may be able to lower the expected collective dose while still reducing decontamination costs below those in the base case. DECON was used to design a decontamination program with different cleanup levels for each surface. This is shown in Figure 5.15, which reproduces part of the assumptions list for this case. As previously noted, the asterisk (*) seen to the left of several of the values indicates a departure from the default values. It should be emphasized that the values we have selected for the exposure factors are not based on scientific evaluation but rather on judgment.

The DECON results for this strategy show two important effects. The first is that decontamination costs for real property drop dramatically from $710 million in the base case to just $199 million. Unfortunately, the second effect more than offsets this benefit. The cost of decontaminating building contents increases from $661 million in the base case to $1.61 billion. This suggests that one may wish to retain the 0.25 Sv cleanup criteria for building contents while still adopting the criteria in Figure 5.15 for the remaining surfaces categories.

5.7 CONCLUSIONS

We have considered the relative magnitudes of accident consequences for several scenarios involving different accident severities and meteorologies. The SST2/Pasquill D scenario was selected for additional analysis. A cost/risk analysis was applied to this scenario to demonstrate the selection of an appropriate cleanup level. We then evaluated several different strategies for restoring the contaminated site. The first was to apply a pre-rain cleanup to see how much we could reduce losses by vacuuming some exterior surfaces before a rainfall. We found that decontamination costs would be reduced by 12%.

***** EXPOSURE FACTORS *****

SURFACE	FACTOR	SURFACE	FACTOR
AGRICULTURAL FIELDS	1.00	LAWNS	* 2.00
ORCHARDS	1.00	EXT. CONCRETE WALLS	* 3.00
VACANT LAND	*15.00	AUTO EXTERIORS	* 3.00
WOODED LAND	*15.00	AUTO INTERIORS	1.00
EXT. WOOD WALLS	* 3.00	AUTO TIRES	* 4.00
EXT. BRICK WALLS	* 3.00	AUTO ENG/DRV TRAIN	* 5.00
LINOLEUM FLOORS	* .50	....INTERIOR GLASS	* .50
WOOD FLOORS	* .50	OTHER PAVED ASPHALT	* 1.50
CARPETED FLOORS	* .50	OTHER PAVED CNCRETE	* 1.50
CONCRETE FLOORS	* .50	....EXTERIOR GLASS	* 3.00
INT'R WOOD/PL WALLS	* .50	RESERVOIRS	1.00
INT'R CNCRETE WALLS	* .50	HARD-SURF FURNSHNGS	* .50
ASPHALT STRTS/PRKNG	*10.00	SOFT-SURF FURNSHNGS	* .50
CNCRETE STRTS/PRKNG	*10.00	ELECTRONIC EQUIP	* .50
ROOFS	*10.00	PAPER PRODUCTS	* .50

Figure 5.15. Exposure Factors

In the next case, we wanted to determine how much decontamination costs would increase if the radiological waste generated during the cleanup was taken off-site for disposal at a licensed facility. The difference here was quite dramatic: total decontamination costs quadrupled.

Next we considered treating wooded areas differently from other surface categories; namely, we applied a fixative to them and then restricted access. This option decreased the decontamination costs of real property by nearly 60%.

We then assumed a potential risk to underground water supplies and prohibited the use of decontamination operations that use water on outside surfaces. The effect of the restriction was to add 39% to the cost of decontaminating the real property.

The final strategy was to apply different cleanup criteria to different surface categories. This strategy showed considerable promise for surfaces other than those associated with building contents, causing decontamination costs for real property to fall from $710 million to just $199 million. However, the cost of decontaminating building contents assumes a major share of the total decontamination costs in the base case, and halving the cleanup criteria causes these costs to escalate by about $1 billion.

APPENDIX A

A.0 INTRODUCTION

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

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

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

There are two general approaches to estimating the cost of a particular operation. The first is to construct the cost from information abut the production function--i.e., the relationship between physical inputs and output(s)--and the various input prices. The second approach establishes, from people actually performing the operation, how much it costs them to perform the operation. Both approaches have problems. In the first, one runs the risk of

overlooking an important input or otherwise mis-specifying the production function. The second method may yield misleading results if the sources are subject to some special conditions such as a regulation, or subsidy, or if the source enjoys any substantial market power.

Where possible, we tried to establish cost and productivity data by the second method. We contacted sources that provide or use the operations in which we were interested. Of course, several of the operations apply only to radiological decontamination; they are not, therefore, customarily supplied in the marketplace. In those cases we had to resort to estimating a crude production function, and we calculated average costs based on the costs of individual inputs. Throughout, when specific labor costs were not available, we usually assumed the hourly cost for labor to be $17.45 per hour. This is the hourly billing cost for common building laborers reported in Means' Construction Costs Data 1982. This figure includes benefits, administrative overhead, and profit. Other rates were used when the required level of skill was high. To the extent that this labor cost figure is too high or too low, the cost figures and input shares of cost reported should be adjusted accordingly.

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

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

One related point is that throughout the report, unit costs and production rates were adjusted to account for radiation control measures. In particular, we assumed that one hour of productive work out of every eight-hour shift was lost due to such things as the necessity of working in cumbersome protective clothing and periodic personnel and equipment decontamination. The cost of this extra hour, therefore, results in a higher cost per sq meter. In situations involving severe contamination, this extra hour may still be inadequate, necessitating appropriate adjustments to the cost data. No adjustments to the costs have been made for the fact that the work is being done in a hostile (radiological) environment. Because the appropriate premium that would have to be paid for labor and equipment is speculative, this adjustment was left to the analyst.

Some operations involve two or more distinct steps. For example, resurfacing paved roads requires first that the surface be planed and second that a layer of asphalt be applied. It is frequently the case that the constituent procedures of an operation have different hourly production rates. The rule for combining procedures of different rates is to make the rate of the total operation equal to the rate of the procedure with the highest cost per sq meter.

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

In the following sections, we develop the data for operations used for 30 surface categories. These categories fall under the broader headings of 1) Land Surfaces, 2) Reservoirs, 3) Structures, 4) Building Contents, and 5) Automobiles. A sixth heading consisting of other activities such as surveying and monitoring, hauling, and waste burial concludes this appendix.

A.1 LAND SURFACES

Several types of land surfaces are addressed in this section. They are agricultural fields, orchards, vacant land, wooded areas, asphalt and concrete streets, roads and parking, other asphalt and concrete surfaces and lawns.

A.1.1 Agricultural Fields

Agricultural fields include lands planted and harvested on an annual or more frequent basis. Crops are primarily grains and vegetables. The cost of most operations would be affected by the time in the crop growing cycle in which the fields were contaminated and in which the decontamination operations were undertaken.

A.1.1.1 Low-Pressure Water

There are several ways in which water could be applied to a field. The simplest would be to use an existing irrigation system, should one be present. However, since many fields--especially those for raising grain--are not irrigated, the cost of applying water is estimated for application using a tank truck with spreader or spray capability. Data used include that for applying water to paved surfaces (see Section A.1.5.2). This is adjusted to account for the slower rate of application resulting from driving on soft dirt rather than on pavement, and also for a longer time to refill the tank. The slower vehicle speed has a relatively small effect on cost, however, since vehicle speed must be slow in either case in order to apply sufficient water. The most important factor affecting cost is the time required to refill the tankers. Where water sources are not available nearby, the cost will be much greater.

In Section A.1.5.3, equipment for applying high-pressure water to pavement is described. This consists of a tank truck equipped with a pump and a laterally-mounted, ten-foot spray bar. Similar equipment could be used for

applying water to agricultural fields, though it would not be necessary to apply the water at high pressure. Another alternative is to use a water distributor truck as is used in road construction. These sorts of equipment configurations should not have significantly different costs.

Here, following the discussion in A.1.5.3, we use an hourly labor cost of \$19.75 and an hourly equipment cost of \$27.37. This gives a total cost of \$47.12 per hour.

The rate of surface coverage is crucial in estimating the cost per unit area. For applying water to pavement with this equipment, a vehicle speed of one mile per hour while spraying was assumed. There would seem to be no real problem in maintaining the same average vehicle speed on agricultural fields. The difference in overall rates will occur as a result of different refill times. In irrigated farm areas, refill times may be no longer than for roads. However, because in dryland areas water sources may be some distance away from the treatment area, we assume that on average the application rate will be 80 percent of what it is for paved roads.

The rate is, therefore:

$$2686\ m^2/hr \times 0.80 = 2149\ m^2/hr$$

Dividing the hourly production rate into the hourly cost figures yields \$0.0092 per sq meter for labor, \$0.0127 per sq meter for equipment, and \$0.0219 per sq meter total.

A.1.1.2 Fixative

The term "fixative" refers to any material used to bind radioactive particles to a surface. Fixing radioactive contamination to a surface will prevent resuspension of the particles in the air by wind or by other physical disturbance. This will help prevent the spreading of contamination, recontamination of treated surfaces, excess contamination of equipment, and additional radiation hazard to personnel. There are a number of materials that could be used for this job, including petroleum-based products such as road oil, emulsified asphalt, and MC-70. Other products that might be useful include those that are sold for the purpose of dust control. These are sometimes called "dust palliatives," "dedustants," or "dust retardants" and include generic products such as calcium chloride, magnesium chloride, and calcium lignosulfate, and proprietary products such as Coherex and Compound SP.

In addition, there are other materials that could be used as fixatives, although that is not their primary function. For example, an application of strippable coating would be effective, though relatively costly (see A.1.5.6). Also, decontaminating foam could be considered a very short-lived fixative (see A.1.5.5). In some circumstances, even plastic sheeting or water

could be used to prevent resuspension of radioactive particles. The important aspects in the choice and application of a fixative are discussed in the remainder of this section.

The use and costs of road oil as a fixative are presented elsewhere in this Appendix (e.g., Section A.1.5.10), so it is not necessary to repeat in detail these findings. The essential points are that road oil can be used as a fixative, and the cost of the material is about $0.31 per sq meter. The term "road oil" actually refers to a number of products having differing viscosities. These are classified as SCs, and common grades are SC-70, SC-250, SC-800, and SC-3000. Road oil does have certain disadvantages. It is quite messy and, in that respect, may diminish property values and raise cleanup costs. Also, because road oil contains a diesel-like dilutant, it is slow curing, remaining sticky for an extended period of time. This can be an advantage to the extent that it continues to capture, as well as hold, dust for an extended period. Finally, widespread application of road oil may have damaging environmental effects.

Another petroleum-based product, MC-70, is used by Reynolds Electrical and Engineering Company, Inc. (REECo), at the Nevada Test Site. According to sources at Chevron Asphalt Co. and Shell Oil Co., MC-70 is a "cut-back asphalt"; that is, asphalt diluted, or "cut back," with a kerosene distillate. There are several MC products, such as MC-70, MC-100, MC-250, MC-800, and MC-3000. The higher-numbered MCs have greater viscosity, which is controlled by the amount of dilutant. MC-70, being of low viscosity, has high penetrating power due to the relatively high proportion (45%) of dilutant.

MC-70 is applied at 110-135°F. The normal coverage is from 0.1 to 0.5 gallon per sq yard, more of the product being required when the soil is porous and absorbent. After curing, MC-70 will form a thin membrane over the soil surface. However, this membrane would break if someone were to walk on it or drive a vehicle over it.

Prices of MCs vary by grade (viscosity), location, and manufacturer. Chevron, which does not sell MC-70, said its price for MC-100 ranges from about $185 to $215 per ton with 255 to 260 gallons per ton (at 60°F). This comes to about $0.78 per gallon. Shell quoted a price of $165 per ton, F.O.B. its plant in California. At 7.93 pounds per gallon, this comes to 252 gallons per ton, or about $0.65 per gallon. Assuming an average coverage rate of 0.4 gallon per sq yard, the cost per sq meter works out to

$$\$0.78/\text{gal} \times 0.4\ \text{gal/yd}^2 \times 1.09\ \text{yd}^2/\text{m}^2 = \$0.34/\text{m}^2$$

for the Chevron price, and

$$\$0.65/\text{gal} \times 0.4\ \text{gal/yd}^2 \times 1.09\ \text{yd}^2/\text{m}^2 = \$0.28/\text{m}^2$$

for the Shell price. Since the Shell price is F.O.B. its plant, $0 34 per sq meter is taken as a representative figure for MC-70 (or MC-100).

According to the source at Chevron Asphalt, emulsified asphalt may be a better choice for a soil fixative for three reasons. First, it does not have to be heated before application. Second, since it is water based, it is easier to handle. Third, it is less costly than road oil or MC-70. Prices range from $135 to $150 per ton according to Chevron and Shell. At 8.3 pounds per gallon, the per-gallon price is from $0.56 to $0.62. Applied at 0.4 gallon per sq yard, the cost of the material would be from $0.27 to $0.30 per sq meter. We take the higher figure as representative. Possible drawbacks to using emulsified asphalt are reduced penetrating power and a tendency of the treated soil to ball up when a vehicle is driven over it.

Additional discussion of petroleum-derived fixatives is given in Section A.1.5.8 (tack coat) and Section A.1.5.9 (sealer).

Coherex is made by the Witco Co. This product is a liquid emulsion of petroleum resins, making a "clean" material compared with MCs, road oil, and emulsified asphalt. Further advantages are that Coherex is non-toxic and is diluted with water for application. In consequence, the environmental problems are significantly less with this product than with the other petroleum-based products. Coherex is commonly used on dirt roads and to protect stockpiles, such as those of coal, from producing dust.

Before application, Coherex is mixed with water in ratios ranging from one part Coherex to four parts water, to a ratio of one part Coherex to twenty parts water. The 1:20 ratio is used with frequent repeat applications, as would be necessary on surfaces with frequent vehicle or foot traffic.

When purchased in bulk, the price is $0.95 per gallon F.O.B. The shipping cost from the Bakersfield, California, plant to the state of Washington, a distance of about a thousand miles, would be about $0.30 per gallon. If we use this as a representative shipping cost, the total cost per gallon is about $1.25. The company's representative explained that a typical application would involve a dilution of five parts water to one part Coherex. This mixture would be applied at about 0.75 gallon per sq yard. This implies a cost of $0.19 per sq meter for the product and for shipping, but not including the cost of application. The mixture is applied as a spray using water tank trucks. This 1:5 mixture would normally last for about six months, when the application should be repeated. Thereafter, annual applications should suffice. This means that, unlike other decontamination steps which, once accomplished, have permanent effects, the cost of the fixative is a function of the desired duration of the dust suppression. Further, since applications involve costs through time, the cost of a fixative of any particular duration requires discounting. The algebraic expression of the cost of a fixative requiring repeated applications with the timing pattern just described discounted back to the date of the initial application is

$$C = c_0 + \frac{c_{1/2}}{(1+r)^{1/2}} + \frac{c_1}{(1+r)^1} + \frac{c_2}{(1+r)^2} + \ldots + \frac{c_{j-1}}{(1+r)^{j-1}}$$

$$= \sum_i \frac{c_i}{(1+r)^i} \quad i=0, 1/2, 1, 2, \ldots, j-1$$

where C = present value of fixative costs
c_i = cost of the i^{th} application
j = desired duration
r = discount rate

If the application costs are all the same, such that

$$c_i = c \text{ for all } i$$

then

$$C = c \sum_i \frac{1}{(1+r)^i} \quad i=0, 1/2, 1, 2, \ldots, j-1$$

Another product that could be used as a fixative is Compound SP, made by Johnson March, Inc. This is an organically based long-chain polymer. It can be sprayed on with an orchard sprayer or a spreader truck as is used to apply road oil. The result is a clear, crusty latex surface coating. Sold in 55-gallon drums, the liquid is applied undiluted at about 1 gallon for 100 sq feet, which is equivalent to 0.09 gallon per sq yard, or 0.11 gallon per sq meter. Coated surfaces should have 24 hours to cure without rain. After that period, the coating will withstand heavy rain.

There are actually two SP products, SP-301 and SP-400. A coating of Compound SP-301 will last about a year. When buying in large quantities (more than 45 drums), the price is $2.15 per gallon. At one gallon per 100 sq feet, the cost per sq meter is $0.23. With the addition of an assumed $0.30 per gallon shipping cost, the cost per sq meter would be about $0.26.
The present value of the cost of using Compound SP-301 as a fixative for a duration of j years can be calculated in the following manner:

$$C = c \sum_i \frac{1}{(1+r)^i} \quad i=0, 1, 2, \ldots, j-1$$

The terms here have the same definitions as before. This formulation assumes that each application has the same (undiscounted) cost.

The other product, SP-400, is more concentrated and will last three to four years. At $3.95 per gallon, the cost per sq meter is about $0.42. With a shipping cost of $0.30 per gallon, this cost per sq meter will rise to $0.46. Assuming that each application will last for three years, the present value of the fixative cost for a duration of j years is

$$C = c \sum_i \frac{1}{(1 + r)^i} \quad i=0, 3, 6, 9, \ldots, j-3$$

Again, all terms have the same meaning as before, and it is assumed that each application will have the same (undiscounted) cost.

Compound SP forms a coating over the soil, but this coating will not support a load. While it has some flexibility, if it is deformed more than 0.25 or 0.50 inches, it will break. Once broken, wind can lift and rip the coating, because Compound SP does not penetrate the soil. Compound SP will transmit moisture, and it will not prevent plants from growing. In fact, sprouting plants will puncture the membrane and might reduce its effectiveness. Compound SP could be used on other surfaces such as roofs or walls. However, since the material will bind with the surface like paint, it cannot be removed easily.

The Dow Chemical Company makes and sells calcium chloride in pellet, flake, and liquid forms for the purpose of dust control. The trade names for these products are Peladow, Dowflake, and Liquidow, respectively. According to the manufacturer, calcium chloride works by attracting moisture from the air as it tries to return or remain in its natural liquid state. It then forms a thin liquid coating over the material on which it is placed. The moisture increases interparticle cohesion in the same manner as does water applied to dusty soil. The chemical has a tendency to hold the moisture so that dust suppression is maintained. However, in very arid areas the soil will dry out, necessitating periodic applications of water.

Glenn Clayton, with REECo, advised that two products with which his company has had good success in dust suppression, and which he feels would also work well as fixatives, are Polybinder and magnesium chloride. Both of these products are purchased from Burris Oil in Las Vegas, Nevada. The following information on these two fixatives was obtained from these sources.

Polybinder is a wood pulp product, sodium lignin with sugars. It is sold in liquid form at a price of $0.80 per gallon. With shipping, the cost comes to about $1.25 per gallon. The manufacturer indicated that Polybinder should be diluted with about an equal part of water. The source with REECo said that they applied Polybinder undiluted. This higher concentration is probably necessitated by heavy road traffic. An oil- or water-spreader truck is used to apply the fixative at about 0.5 gallon per sq yard. Polybinder is applied at

air temperature. The normal application rate at the Nevada Test Site is about 6,000 gallons per day per truck, which equals a coverage of 12,000 sq yards per shift.

Magnesium chloride is sold at $0.50 per gallon. With shipping, the cost would be about $0.80 per gallon. According to the manufacturer, magnesium chloride should normally be diluted, with one part magnesium chloride to four parts water. The diluted solution is applied in the same way as Polybinder.

Both products work by drawing and holding moisture from the air. However, according to the source at Burris Oil, Polybinder works better than magnesium chloride. This is due in part to the stickiness of the sugars in Polybinder. Also, both these products have relatively short lives, lasting only about three months.

Using the $1.25 per gallon for the undiluted Polybinder and $0.80 per gallon for the magnesium chloride, we can calculate the cost of materials per sq meter. For Polybinder the cost is

$$\$1.25/\text{gal} \times 0.25 \text{ gal Poly./gal diluted sol} \times 0.5 \text{ gal/yd}^2$$
$$\times 1.1947 \text{ yd}^2/\text{m}^2 = 0.19/\text{m}^2$$

For magnesium chloride the cost is

$$\$0.80/\text{gal} \times 0.2 \text{ gal m.c./gal diluted sol} \times 0.5 \text{ gal/yd}^2$$
$$\times 1.1947 \text{ yd}^2/\text{m}^2 = 0.10/\text{m}^2$$

No single fixative is clearly superior for all instances in which a fixative might be applied to agricultural fields. Here we use Coherex as the fixative. This has a cost of $0.19 per sq meter when applied using a 1:5 mixture with water.

The equipment to apply the fixative is basically the same as that described in Section A.1.5.3 for applying high-pressure water to pavement. Here, high pressure is neither necessary nor desirable. Further, it is not necessary to apply as much volume of material per sq meter as with the water treatment. Therefore, the spray truck can move forward at a somewhat faster rate. In this case a vehicle speed of 1.36 miles per hour is appropriate when the pump rate is 100 gallons per minute and the spray width is ten feet.

A 5000-gallon capacity tank truck will be emptied in 50 minutes with a 100 gpm spray rate. The assumed refill time for water in Section A.1.5.3 is 30 minutes. Here we raise the assumed refill time to 50 minutes to account for mixing of the fixative with water and the likelihood of a greater travel

distance to the refill location. Alternatively, the spray truck could be supplied by "feeder" or "nurse" trucks, though it is not clear that this would result in any cost savings.

Since spray and refill times are equal, 3.5 of seven hours will be spent spraying. Therefore, 4.2 loads will be applied per shift. Coverage per shift hour is

$$3.5 \text{ hr} \times 1.36 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.0929 \text{ m}^2/\text{ft}^2$$
$$\div 8 \text{ hr/shift} = 2922 \text{ m}^2/\text{hr}$$

This rate is divided into the hourly cost figures as shown:

$$\text{Labor:} \quad \frac{\$19.75/\text{hr}}{2922 \text{ m}^2/\text{hr}} = \$.0068/\text{m}^2$$

$$\text{Equipment:} \quad \frac{\$27.37/\text{hr}}{2922 \text{ m}^2/\text{hr}} = \$0.0094/\text{m}^2$$

Adding the material cost to these two figures yields the total cost per sq meter: $0.2061.

A.1.1.3 Leach

In some circumstances it may be acceptable to leach the contaminant into the soil. This would not be the case where doing so would pose a threat of contamination to underground water supplies. Another consideration is root uptake, which could cause exposure via the food ingestion pathway. This suggests that an acceptable strategy in agricultural fields may be to leach the contaminant to a short distance below the root depth but no further. Leaching agents that either lose their effectiveness or release the contaminant while picking up other chemicals in the soil could be used in this strategy.

EDTA (ethylenidiaminetetraacetic acid) is one candidate for leaching. According to a technical services representative at Dow Chemical Co., it is used frequently for decontaiminating surfaces in nuclear reactors. It is particularly effective for removing radioactive scale. EDTA is a chelating agent, meaning that it will bind with metal ions and keep them soluble. Since EDTA is oxidizable with light or oxygen, it will break down and release the ions to which it had been bound. Therefore, a very careful application of EDTA could be used to transport the contamination from the surface to a desired depth. Besides the rate of oxidation and bacteriological breakdown of EDTA, another factor is the chemical composition of the soil. EDTA will chelate with

other metal ions (notably calcium) present in the soil in addition to the radioactive ones. In general, the amount of preexisting calcium in the soil will determine the amount of EDTA to apply.

Since EDTA is not very water soluble, the sodium or ammonium salt of EDTA is the form in which it is usually sold. Dow markets an EDTA sodium salt under the name of Versene 100. The bulk price is 36.5 cents per pound for this 39 percent active solution. The Dow technical representative suggested that dilution of about twenty parts water to one part EDTA solution, making about a two percent solution, would be a reasonable formulation of an EDTA leaching solution. This wold handle about 1,000-2,000 parts per million of metal ions in the soil.

Another leaching agent that might be used is ferric chloride ($FeCl_3$). This is described in Section A.1.9.3. In that section the cost of applying a one-percent solution is calculated at \$0.0263 per sq meter. Because of this lower cost, leaching here is assumed to be done with ferric chloride. Another reason for basing these computations on ferric chloride is that there is some test data on the effectiveness of this material used for radiation decontamination.

The same equipment and personnel used to apply water to agricultural fields (see Section A.1.1.1) would be used for leaching. However, to apply the necessary greater amount of water, a slower vehicle speed is called for. Experimental data were produced based on an application of 0.30 inches of water-ferric chloride solution (Dick and Baker 1967). This volume requires a vehicle speed of 0.6 miles per hour. As with fixative application (see Section A.1.1.2), the application tank truck would be spraying half the time and refilling half the time. The average coverage per shift-hour is 1814 sq meters. Dividing this result into the hourly labor and equipment costs gives the costs of these inputs on a sq-meter basis.

$$\text{Labor: } \$19.75/\text{hr} \div 1814\ \text{m}^2/\text{hr} = \$0.0109/\text{m}^2$$

$$\text{Equipment: } \$27.37/\text{hr} \div 1814\ \text{m}^2/\text{hr} = \$0.0151/\text{m}^2$$

Summing the labor, equipment, and material costs gives the total cost per sq meter: \$0.052.

A leaching agent would normally be applied with a water tank truck equipped with a spray boom to achieve fairly even application. Following application of the leaching agent, water would be applied either by truck or via an irrigation system.

A.1.1.4 Clear

Clearing refers to removing the plant cover. This operation has two functions. The first is the obvious one of effecting a degree of decontamination

since the removed plant cover will take with it a portion of the radioactive particles. The second function of clearing is to facilitate the execution of subsequent operations. For agricultural fields, most crop cover would not impede other operations.

Deciding whether it is necessary to clear an agricultural field of vegetation depends principally on the amount of vegetation and the operation(s) to follow. For example, clearing a wheat field prior to scraping would probably not be necessary. On the other hand, clearing a corn field on which the crop had nearly reached full growth probably would be a requirement before application of some other treatment such as leaching or scraping.

Besides facilitating subsequent operations, clearing will also remove much of the contamination residing on the vegetation. The efficiency of this procedure would be increased by a prior, possibly aerial, application of a fixative.

In most cases, clearing of agricultural fields would be accomplished using standard harvesting equipment. Since the likelihood that the crop could be cleared increases with the bulk of the crop, it is assumed that corn was the crop to be cleared.

The publication Custom Rates for Farm Operations (May 1979) lists the cost of combining corn at $14-15 per acre plus $0.20 per hundredweight. However, combining is a more involved procedure and probably uses more costly equipment than is necessary. A source in the U.S. Department of Agriculture suggests that a swather would be the best alternative for clearing. Besides removing the plants, it also bundles or bales the crop. The cost per acre is broken down as follows:

Baler twine	$10.80
Machinery and fuel	21.42
Repair	25.89
Labor	33.22
Interest	2.95
Total	$94.28

For our purposes we can group all non-labor costs ($61.06) under equipment.

Swathing requires about 6.52 hours per acre, which is equivalent to 0.15 acres per hour. Multiplying cost per acre by this acres-per-hour figure gives the cost of swathing as $14.47 per hour. The hourly labor cost is $5.10, and the equipment cost is $9.36 per hour. Converting the acres-per-hour figure to sq meters per hour can be done as follows:

$$\frac{4046.7\ m^2/ac}{6.52\ hr/ac} \times 7/8\ \text{adj} = 543\ m^2/hr$$

The hourly costs of the inputs can be calculated by dividing the costs per acre by the number of acres per hour. Dividing again by the number of sq meters per hour gives the cost per sq meter.

$$\text{Total: } \$94.28/\text{ac} \div 6.52 \text{ hr/ac} \div 543 \text{ m}^2/\text{hr} = \$0.027/\text{m}^2$$

$$\text{Labor: } \$33.22/\text{ac} \div 6.52 \text{ hr/ac} \div 543 \text{ m}^2/\text{hr} = \$0.009/\text{m}^2$$

$$\text{Equipment: } \$61.06/\text{ac} \div 6.52 \text{ hr/ac} \div 543 \text{ m}^2/\text{hr} = \$0.017/\text{m}^2$$

This operation requires a farm equipment operator and a swather as the primary inputs.

There is an additional cost for hauling away the cleared material. Since hauling is necessary in connection with several operations, hauling costs are discussed separately in Section A.6.2. However, it is necessary to estimate the volume of material to be hauled. For clearing of agricultural fields, we estimate about 0.10 cubic meters of material per sq meter of surface treated.

A.1.1.5 Scrape

Scraping involves the removal of the top surface of soil. In general, the objective is to remove a thin but as complete a layer as possible. This goal is made difficult by surface irregularities. Further, earth moving equipment has limited precision with respect to removing a thin layer of soil. In consequence, according to several sources listed below, average removal depth will be about four to six inches.

Since earth-moving operations are fairly common, there are a number of sources and considerable information available. Published sources include annual editions of Means' Building Construction Cost Data, Engelsman's Heavy Construction Cost File, and McGraw-Hill's Dodge Guide. Further, industry sources--Doolittle Construction Company, World Excavating and T. E. Knudson, construction consultant--were also contacted for this report. Additional information was also obtained from the Reynolds Electrical and Engineering Co., Inc. (REECo), Joseph M. Hans, Jr., and other reports on decontamination procedures. These reports included Radiological Dose Assessment and the Application and Effectiveness of Protective Actions for Major Property Types Contaminated by a Low-Level Radionuclide Deposition by Julin et al. (1978) and Estimate of Potential Costs of Hypothetical Contaminating Events, Subject to 'Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment' by Battelle-Northwest (1978).