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

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

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

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

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

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

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

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

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

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

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

The cost of operation and maintenance is:

$4.42 x 4/3 = $5.89

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

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

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

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

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

Planing

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TABLE A.1.7.4. Representative Asphalt Road Planing Cost Data

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

A.1.8 Tack Coat

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

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

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

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

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

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

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

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

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

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

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

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

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

Labor: $44.70/hr ÷ 12,890 = $0.0035

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

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

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

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

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

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

A.1.9 Sealer

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

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

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

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

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

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

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

The adjusted cost per square meter can be found by multiplying the cost per square yard by the unadjusted hourly rate to get the hourly cost of labor and equipment. This is then divided by the adjusted hourly coverage in square meters. The unadjusted hourly coverage rate is

$$1000 \text{ yd}^2 \div 8 \text{ hrs/shift} = 125 \text{ yd}^2/\text{hr}$$

The labor and equipment costs are, therefore:

Labor: $$\frac{\$0.30/\text{yd}^2 \times 125 \text{ yd}^2/\text{hr}}{91 \text{ m}^2/\text{hr}} = \$0.41/\text{m}^2$$

Equipment: $$\frac{\$0.09/\text{yd}^2 \times 125 \text{ yd}^2/\text{hr}}{91 \text{ m}^2/\text{hr}} = \$0.12/\text{m}^2$$

Since the material cost per square meter is not affected by the hour lost per shift, the cost per square meter is calculated more simply:

Material: $\$0.43/\text{yd} \times 1.196 \text{ m}^2/\text{yd} = \$0.51/\text{m}^2$

Adding the costs of the three inputs, the total cost per square meter is found to be \$1.04.

For comparison, the Engelsman data for tar and asphalt surface treatments are also given. Both of these coatings are applied at 1.5 gallons per square yard, and the coverage rate is listed at 1500 square yards for both. The adjusted hourly coverage rate is:

$$1500 \text{ yd}^2/\text{shift} \div 8 \text{ hrs/shift} \times 0.836 \text{ m}^2/\text{yd}^2 \times 7/8 = 137 \text{ m}^2/\text{hr}$$

Following the same calculations as for surface sealer, the square meter input costs for tar are calculated as shown:

Labor: $$\frac{\$0.13/yd^2 \times 187.5\ yd^2/hr}{137\ m^2/hr} = \$0.18/m^2$$

Equipment: $$\frac{\$0.06\ yd^2 \times 187.5\ yd^2/hr}{137\ m^2/hr} = \$0.08/m^2$$

Material: $$\$1.00/yd^2 \times 1.196\ yd^2/m^2 = \$1.20/m^2$$

Total: $$\$0.18/m^2 + \$0.08/m^2 + \$1.20/m^2 = \$1.46/m^2$$

The same cost calculations for asphalt are:

Labor: $$\frac{\$0.13/yd^2 \times 187.5\ yd^2/hr}{137\ m^2/hr} = \$0.18/m^2$$

Equipment: $$\frac{\$0.06\ yd^2 \times 187.5\ yd^2/hr}{137\ m^2/hr} = \$0.08/m^2$$

Material: $$\$0.92/yd^2 \times 1.196\ yd^2/m^2 = \$1.10/m^2$$

Total: $$\$0.18/m^2 + \$0.08/m^2 + \$1.10/m^2 = \$1.36/m^2$$

Comparing the Los Angeles Department of Public Works data with the Engelsman sealer data shows a considerable difference. The first source has a total cost of $0.54 per square meter versus $1.04 per square meter from the second source. The apparent explanation for this difference is in the method and scale of operation. This is reflected in the much higher rate reported by the Los Angeles Department of Public Works as compared to the one from Engelsman: 1,933 square meters per hour versus 91 square meters per hour.

There remains the problem of estimating the input costs for the Los Angeles Department of Public Works data. The first step is to estimate labor and equipment costs per square meter using hourly cost figures in Means' Building Construction Cost Data 1982 for the inputs specified by the Los Angeles Department of Public Works. The total hourly labor and equipment costs are estimated as shown in Table A.1.9.1. Means has no listing for labor costs for a mixer man or an asphalt raker. Their wage rates were estimated. Also, the hourly cost of a slurry seal machine was estimated using the hourly cost

TABLE A.1.9.1. Total Hourly Labor and Equipment Cost Estimates for Surface Sealing

	Cost (1982 $/hr)
Labor	
1 Driver-operator	24.95
2 Heavy-truck drivers 8 $19.75	39.50
1 Mixer man (est.)	20.00
2 Asphalt rakers 8 $20.00 (est.)	40.00
1 Building laborer	19.40
Total labor	143.85
Equipment	
1 Slurry seal machine (est.)	31.12
2 Nurse trucks @ $35.72	71.44
Total equipment	102.56

of a 3000-gallon distributor tank truck. The cost of a heavy dump truck was used for the cost of a nurse truck.

Dividing the hourly labor cost by the hourly coverage rate of 1933 square meters gives a cost of $0.07 per square meter for labor. The equipment cost is $0.05 per square meter.

Subtracting labor and equipment from the total cost per square meter leaves $0.42 per square meter for material. This is somewhat less than the cost specified by Engelsman and slightly less than similar surface coating

TABLE A.1.9.2. Summary of Surface Coating Data for Asphalt Roads

Source and Coating Type	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
L.A. Pub Wrks					
Sealer	1933	0.54	0.07	0.05	0.42
Englesman					
Sealer	91	1.04	0.41	0.12	0.51
Tar	137	1.46	0.18	0.08	1.20
Asphalt	137	1.36	0.18	0.08	1.10
Representative					
Sealer	1933	0.54	0.02	0.01	0.51

material costs specified by Means. The reason for this difference could be due to overestimation of combined labor and equipment costs, underestimation of total costs, or because material costs are in fact less per unit area than indicated by the published sources. Here **it** is assumed that, either because the Los Angeles Department of Public Works is able to acquire the material at a lower price or because of thinner application, this material cost estimate is reasonable.

A.1.10 Road Oil

Road oil would be appropriate as a temporary fixative preliminary to either planing or removal of existing pavement. There are other materials which could also be used as fixatives. These are described in Section A.7 _I_ According to the Washington State Department of Transportation, the cost of applying road oil is $270 per ton. **It** is applied at 0.4 gallons per square yard at a speed of about three miles per hour with a swath about 12 feet wide. Since there are about 250 gallons of road oil per ton, the cost per square meter is

$$\frac{\$270/\text{ton}}{250\ \text{gal/ton}} \times 0.4\ \text{gal/yd}^2 \times 1.19599\ \text{m}^2/\text{yd}^2 = \$0.52/\text{m}^2$$

The rate of coverage is

$$3\ \text{mi/hr} \times 5280\ \text{ft/mi} \times 12\ \text{ft wide} \times 0.093\ \text{m}^2/\text{ft}^2 \times 7/8 = 15{,}468\ \text{m}^2/\text{hr}$$

Unfortunately, this source was unable to supply information regarding the separate costs of the various inputs.

While Means' Building Construction Cost Data 1982 does not include road oil application as a specific entry, an estimate of the cost of this operation can be' developed from the Means volume. Page 11 gives the cost of a 3000-gallon distributor tank trailer with a 38-horsepower diesel motor to operate the pump. This distributor is for asphalt, but **it** is assumed that the cost of an oil distributor would not be greatly different. In addition, a truck tractor (p. 13) would also be necessary. The hourly cost of this equipment is calculated as shown in Table A.l.lO.l. The rent in dollars per hour is based on 336 hours (2 shifts) per month.

TABLE A.l.lO.l. Hourly Equipment Cost Estimate for Road Oil Distribution

Equipment	Oper. Cost ($/hr)	Rent ($/mo)	Rent ($/hr)	Total ($/hr)
Distributor	4.66	2500	7.44	12.10
Tractor	10.80	2350	7.00	17.80
Total				29.90

In addition, feeder trucks would be useful where the source of the material was not close. We estimate three feeder trucks per distributor. At $25.00 per hour each, the total equipment cost is $104.90 per hour.

For personnel, five driver operators are appropriate. The extra driver would be available for relief or for equipment operation on the distributor. The billing cost for heavy-truck drivers, according to Means, is $19.75 per hour. Therefore, the total labor cost is $98.75 per hour.

Following the information from the Washington State Department of Transportation, we assume an average vehicle speed of three miles per hour. The assumed application width is ten feet. The coverage rate is, then

$$3 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.0929 \text{ m}^2/\text{ft} \times 7/8 \text{ adj} = 12{,}890 \text{ m}^2/\text{hr}$$

Road oil costs $0.31 per square meter. Multiplying this by the hourly coverage gives an hourly material cost of $3995.90. Total cost comes to $4199.55 per hour. Dividing each of the hourly cost categories by the hourly coverage gives the cost per square meter as shown in Table A.1.10.2. Because of their consistency with each other, these figures are taken as the representative costs for application of road oil. Table A.1.10.3 summarizes the information on the application of road oil.

TABLE A.1.10.2. Costs Per Square Meter for Road Oil Distribution

	Total	Labor	Equipment	Material
$/hr	4199.55	98.75	104.90	3995.90
$/m^2	0.3258	0.0077	0.0081	0.31

TABLE A.1.10.3. Summary of Road Oil Application Data for Asphalt Roads

Source	Rate (m^2/hr)	Cost (1982 $/m^2) Total	Labor	Equipment	Material
Wash. Dept. of Trans.	15,468	0.52	--	--	0.31
Means	12,890	0.326	0.008	0.008	0.310
Representative	12,890	0.326	0.008	0.008	0.310

A.1.11 Thin Asphalt Overlay

Three sources provided information on the cost of placing a thin layer of pavement--one to two inches thick. Such a pavement layer is most likely to be applied after the road surface has been planed. When a new surface of asphalt is put on an asphalt base, the new asphalt is preceeded by application of a tack coat. Beyond its intended function to bind the two layers of asphalt, the tack coat also will fix any existing radiation on the road surface. While the cost of applying a tack coat was listed separately above, the following applications of asphalt on asphalt include the cost of a tack coat in the total.

The Policy Planning unit of the U.S. Federal Highway Administration provided selected data from a Federal Highway Administration publication entitled The Status of the Nation's Highways: Conditions and' Performance, published in January, 1981. In Tables 4-4 through 4-8 the cost of resurfacing roads cross-tabulated by various factors was presented. For example, the cost per mile of resurfacing a one- to three-lane minor collector in a rural area on flat terrain was given as $69,000. In contrast, the cost of resurfacing a four-lane undivided highway in a built-up area is listed as $389,000 per mile. Using the Federal Highway Administration's estimate of 11 feet for lane width, the cost per square meter of resurfacing varied from $1.42 to $23.60. The former figure was for a minor collector on flat terrain in a rural area and includes six to eight feet of shoulder on each side of the road. The higher figure is for a pavement overlay on two lanes plus shoulders of an urban undivided highway in a built-up area. Neither the tables nor personal conversation made it quite clear why the cost of resurfacing a road was so highly variable and so sensitive to the type of area. Also, no data were available describing the inputs or the relative magnitudes of their costs. After adjusting for reduced productivity because of hazardous environment, these figures range from $1.62 to $26.97.

The State of Washington Department of Transportation reported that the cost of putting a one- to 1.5-inch layer of asphalt on existing pavement costs about $1.50 per square yard, or about $1.79 per square meter. In addition to this amount, the source advised that an extra ten percent should be included for "mobilization." This involves getting the equipment to the site and so forth. The cost, including the extra ten percent and one hour adjustment, is $2.25 per square meter.

This paving operation requires a mobile asphalt plant, a front-end loader, two tanker trucks to supply asphalt, a paving machine, three rollers, and ten trucks. The personnel required would be three operators for the asphalt plant and the loader, two teamsters for the asphalt supply trucks, five operators for the paving machine and the three rollers, ten drivers for the trucks, and two laborers.

According to this source, paving is about three times faster than planing, meaning that the speed for paving is nine lane miles per day. Adjusting for one hour per shift lost to radiation control activities, the average hourly production is:

$$9 \text{ mi} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8 \div 8$$
$$= 4834 \text{ m}^2/\text{hr}$$

The Los Angeles Department of Public Works reported that resurfacing costs $25.80 per ton of asphalt placed. This source added that a ton of asphalt will cover 160 square feet, one inch deep. This is a surface area of 14.88 square meters. Thus the cost per square meter, with productivity adjustment, is:

$$\frac{\$25.80/\text{ton}}{14.88\ \text{m}^2/\text{ton}} \times \frac{8}{7} = \$1.98/\text{m}^2$$

This source explained that their paving machine is capable of applying 600 tons of asphalt per hour. This represents about 1.8 lane miles per hour or, equivalently, 8928 square meters per hour. However, they cannot achieve this rate, since their asphalt plant only produces 1500 tons of asphalt per day. Even so, their actual paving rates do not fully utilize the asphalt plant's capacity. In a very good day, 1000 tons are applied. In a normal day, approximately 800 tons are applied. Adjusting for loss of a shift hour for special radiation control activities, 700 tons per day represents a better expectation for paving in a contaminated environment. This will cover slightly over two lane miles. The average coverage rate is 1302 square meters per hour.

Information taken from Means Site Work Cost Data 1982 (p. 75) and from Engelsman's 1981 Heavy Construction Cost File (p. 140) were in close agreement, but differed significantly from cost data supplied by the Washington State Department of Transportation and the Los Angeles Department of Public Works. As can be seen in Table A.1.11.1, rates from Means and Engelsman are very close to each other but very much below the other two. Also, the costs reported in the two volumes are higher than the costs reported by the two governmental agencies. We can offer no explanation for the discrepancy.

Because the Means publication provides a relatively consistent set of data for this and other operations, and also because exactly the same sorts of adjustments are used for other operations, these adjustments are described in detail here. To apply an inch and a half thick layer of asphalt, Means calls for a crew consisting of one foreman at $22.25 per hour (billing cost), seven building laborers at $19.40 each, and two medium-equipment operators at $24.95. The total hourly labor cost comes to $158.05. The equipment required includes a paving machine which costs $68.05 per hour and a ten-ton roller at $20.51 per hour, bringing the total equipment cost to $88.56 per hour.

TABLE A.1.11.1. Summary of Cost and Productivity Data for Paving Asphalt Roads with a One-Inch Layer of Asphalt

Source	Rate (m^2/hr)	Cost (1982 $\$/m^2$)			
		Total	Labor	Equipment	Materials
Fed. Hyw. Admin.	--	1.62 - 26.97	--	--	--
Wash. Dept. of Trans.	4834	2.25	--	--	--
L.A. Pub. Works	1302	1.98	--	--	--
Means	453	2.34	0.35	0.19	1.81
Engelsman	320	3.01	0.42	0.30	2.29
Representative	453	2.34	0.35	0.19	1.81

Multiplying the hourly production by the cost per square yard gives the total hourly cost:

$$\frac{3300\ yd^2/day}{8\ hr/day} \cdot \$2.87/yd^2 = \$1183.88/hr$$

Subtracting the hourly labor and equipment charge from this amount gives the hourly material cost:

$$\$1183.88 - (\$158.05 + \$88.56) = \$937.27$$

Next **it** is necessary to calculate the effective application rate in terms of square meters per hour. There are three adjustments to be made. One is to convert from square yards to square meters. The second is to adjust for one hour per shift lost to radiation control measures. The third adjustment is to convert the figures to reflect a pavement thickness of 1.0 inch rather than 1.5 inches. The method for dealing with this last adjustment becomes apparent when **it** is noted that there is a consistent relationship between different thicknesses of pavement, the rate of application, and the cost per square yard. Specifically, the Means data shows that doubling the pavement thickness results in halving the coverage rate and doubling the cost per unit area. Therefore, adjusting the application rate from 1.5-inch thickness to 1.0 inch requires multiplying by 1.5. Thus, the adjusted rate is

$$412.5\ yd^2/hr \times 0.836\ m^2/yd^2 \times 7/8 \times 1.5 = 453\ m^2/hr$$

The material cost per unit area is not subject to the one hour in eight adjustment for reduced productivity and decontamination. Therefore, to calculate the cost of material per square meter at one-inch thickness, the following steps are taken to convert the material cost per hour:

$$\frac{\$937.27/hr}{412.5\ yd^2/hr \times 0.836\ m^2/yd^2} \times \frac{1.0}{1.5} = \$1.81/m^2$$

The labor and equipment costs per square meter are calculated by simply dividing the hourly cost by the hourly production as shown:

Labor: $\frac{\$158.05/hr}{453\ m^2/hr} = \$0.35/m^2$

Equipment: $\frac{\$88.56/hr}{453\ m^2/hr} = \$0.19/m^2$

The total cost per square meter is the sum of the three input categories, or $2.34 per square meter.

The disparity in the rates presents the greatest difficulty in specifying representative data for this operation. The Means data was selected as representative. There are several reasons for this. One is the consistency of this data with other operations in this report. Second is the internal consistency among the input categories. Further, the total per square meter is close to the average of all four data sources, and while the rate is somewhat lower than the average, it is one of the middle two rates reported. Moreover, the hazardous environment may make this rate more appropriate than the higher ones. Finally, this rate is consistent with the input costs per square meter in that the associated cost per hour is reasonable for the specified inputs.

A. 1.12 Resurface

Resurfacing asphalt pavement involves two previously described operations: planing away the top surface, followed by paving with a one-inch layer of asphalt. Paving is the faster and also the more costly procedure. Adjusting the scale of the planing step to that of paving requires 2837 ÷ 750 = 3.78 planing crews for every paving crew. The costs per square meter of the combined operation are simply the sum of the costs of the separate operations. Table A.1.12.1 summarizes this discussion.

TABLE A.1.12.1. Summary of Asphalt Road Resurfacing Data

Procedure	Crews	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Plane	3.78	750	0.91	0.35	0.56	--
Pave	1	2837	2.02	0.11	0.10	1.81
Total	1	2837	2.93	0.46	0.66	1.81

A.1.13 Medium-Thickness Asphalt Overlay

In Section A.1.11 the representative cost of paving asphalt with a one-inch layer of new asphalt was developed. The basis for these figures was primarily information from the Washington State Department of Transportation and the Los Angeles Department of Public Works and, to a lesser extent, Means' Building Construction Cost Data 1982. These sources were also used to develop a consistent estimate of representative costs and the rate for paving a three-inch layer of asphalt.

Data in Means (p. 47) indicates that the costs and rate of paving remain constant with the volume of pavement applied. Thus, doubling the pavement thickness will halve the application rate and double the cost per unit area. Using this relation, the costs and rate developed in Section A.l.ll for paving a one-inch layer can be transformed to a three-inch layer. The results are sumnarized in Table A.1.13.1.

An overlay of asphalt will reduce measurable radiation by shielding and preventing resuspension. Without any actual removal of radioactive particles, a three-inch layer of asphalt will reduce emitted radiation by half.

TABLE A. 1.13.1. Representative Data for Paving Asphalt Roads with a Three-Inch Layer of Asphalt

Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Materials
946	6.06	0.33	0.30	5.43

A. 1.14 Removal and Replacement

Means Site Work Cost Data 1982 (p. 22) lists the cost of removing asphalt pavement at \$2.23 per square yard, using one equipment operator to run both a backhoe and a hydraulic demolition hammer, plus two laborers. Labor makes up 51 percent of the costs excluding overhead, or 40 percent of total costs, while equipment accounts for 49 percent of the costs excluding overhead and profit and 39 percent of costs including overhead and profit.

The production rate is listed at 390 square yards per day. With one hour per shift lost for radiation control, the average hourly production is 35 square meters. The cost per square meter is \$3.05.

Means (p. 75) lists asphalt paving costs for thicknesses up to four inches. To standardize to a thickness of six inches, costs were adjusted upward by twice the amount that costs increased from three to four inches. Specifically, costs in 1982 dollars per square yard were given as shown in Table A.1.14.1.

TABLE A.1.14.1. Means Cost Data for Asphalt Paving

Thickness	Cost (1982 \$) Material	Labor	Equip.	Total	Total, incl. Overhead & Profit
3"	3.80	.70	.40	4.90	5.60
4"	5.10	.97	.54	6.61	7.60
6" (est)	7.70	1.31	.82	9.83	11.60

Total cost rose by \$2.00 per square yard when thickness was increased by one inch from three to four inches. This cost per inch was applied to the increase of two inches from four to six. Thus \$4.00 were added to the \$7.60 listed for the four-inch thickness, bringing the total to \$11.60 per square yard for a six-inch thickness. Other cost categories were adjusted in a similar manner. The cost per square meter is \$13.87. The production rate was estimated at 550 square yards per day. After adjustments, this comes out to 50 square meters per hour and a unit cost of \$15.85 per square meter.

Engelsman's 1981 Heavy Construction Cost File (p. 56) estimates the cost of removing asphalt paving over six inches thick at $0.82 per square yard. Adjusting the daily output of 1000 square yards by 7/8, the implied average hourly production is 91 square meters. The adjusted cost is $2.12 per square meter. The cost breakdown is 40 percent for labor and 60 percent for equipment.

The State of Washington Department of Transportation estimates the cost of removing six inches of asphalt pavement at $2.50 per square yard. With adjustments, this implies a cost of $3.42 per square meter. To replace the same surface costs $8.75 per square yard. The same adjustments bring the cost per square meter to $11.96.

The City of Los Angeles Department of Public Works lists a combined removal and replacement cost as $45.70 per ton of asphalt placed. They further estimate asphalt placement costs at $25.80 per ton. The difference, $21.70 per ton, refers to the volume of material removed. Since a ton of asphalt occupies 13.33 cubic feet, these costs refer to an area of 26.66 square feet of pavement six inches thick. These figures are equivalent to $7.32 per square yard for removal. After adjustments, this comes to $10.01 per square meter. This figure is clearly much higher than those given previously. No explanation can be offered for this difference.

The paving cost at $25.80 comes to $11.90 per square meter after adjustments.

The Federal Highway Administration supplied data in the form of selected tables from The Status of the Nation's Highways: Conditions and Performance. As mentioned previously in the discussion of applying a thin pavement overlay, these data consist of widely varying unit costs that generally seem to be much higher than costs supplied by other sources. Further, these data apply to all road construction materials. The combined costs for removal and replacement run from $8.34 per square meter for a rural minor collector four lanes or more wide on flat terrain, to $112.49 per square meter for two lanes' width of an urban freeway in a built-up area. These figures have been adjusted to account for radiation control measures.

The representative unit cost of removal was calculated as the average of the asphalt removal costs, excluding those for the Los Angeles Public Works Department. All of the replacement costs were averaged to get the representative cost. Representative input costs are based on the percentage of total costs for the inputs as reported by Means and Engelsman. These percentages were averaged between the two sources, and then the average percentage was applied to the corresponding representative total cost. Representative production rates are averages of the reported rates. The representative cost data for concrete surfaces are all calculated as averages. The rate for the combined removal and replacement operation is set at 71 square meters per hour, the rate of the more costly replacement procedure. This implies that there will be 71/63 = 1.13 removal crews per replacement crew.

TABLE A.1.14.2. Summary of Pavement Removal and Reconstruction Cost and Productivity Data

Source Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
		ASPHALT SURFACES			
Means					
Removal	35	3.05	1.22	1.83	--
Replacement	50	15.85	2.06	3.17	10.62
Total		18.90	3.28	5.00	10.62
Englesman					
Removal	91	1.12	0.45	0.67	--
Replacement	91	11.78	1.65	0.94	9.19
Total		12.90	2.10	1.61	9.19
Wash. Dept. of Trans.					
Removal	--	3.42	--	--	--
Replacement	--	11.96	--	--	--
Total	--	15.38	--	--	--
L.A. Pub. Works					
Removal	--	10.01	--	--	--
Replacement	--	11.90	--	--	--
Total	--	21.91	--	--	--
Representative					
Removal	63	2.53	1.01	1.52	--
Replacement	71	12.87	1.67	1.80	9.40
Total	71	15.40	2.68	3.32	9.40

A.2 CONCRETE ROADS

Most of the operations for concrete roads are the same as for asphalt roads. Therefore, for many of the operations on concrete roads, the reader is directed to the section describing the corresponding operation on asphalt roads. Where significant differences exist, they are noted.

A.2.1 Vacuum

The vacuuming of concrete pavement is the same as vacuuming asphalt pavement. See Section A.1.1.

A.2.2 Low-Pressure Water Wash

A low-pressure water wash of concrete pavement is the same as a low-pressure water wash of asphalt pavement. See Section A.1.2.

A.2.3 High-Pressure Water Wash

A high-pressure water wash of concrete pavement is the same as a high-pressure water wash of asphalt pavement. See Section A.1.3.

A.2.4 Very High-Pressure Water Wash

A very high-pressure wash of concrete pavement is the same as a very high-pressure wash of asphalt pavement, except that concrete pavement is less likely to be eroded by this procedure. See Section A.1.4.

A.2.5 Foam

See Section A.1.5.

A.2.6 Strippable Coating

See Section A.1.6.

A.2.7 Planing

Planing is described in Section A.1.7. According to the Los Angeles Department of Public Works, planing concrete takes about 20% more time than planing asphalt. Therefore, the representative asphalt planing data from Section A.1.7 are adjusted to account for this slower rate, holding hourly costs constant. The rate for planing concrete is 625 square meters per hour. The total cost is $1.09 per square meter, of which labor accounts for $0.42 and equipment accounts for $0.67.

A.2.8 Tack Coat

See Section A.1.8.

A.2.9 Sealer

See Section A.1.9.

A.2.10 Road Oil

See Section A.I.IO.

A.2.11 Thin Asphalt Overlay

Currently, asphalt is the preferred paving material over concrete in most situations. While a new asphalt surface on an existing asphalt base generally poses no particular difficulties, asphalt surfacing on a concrete base could. Because concrete is rigid, cracked concrete can rock as the vehicle load moves across it. This rocking can result in the breaking up of an asphalt coating unless the coating is fairly thick. For this reason, the Los Angeles Public Works Department never uses less than two inches of asphalt on a concrete base. On the other hand, the State of Washington Department of Transportation reported that they maintained their minimum thickness of an asphalt overlay on concrete at 1 to 1.5 inches, the same as over an asphalt base.

In this report it was assumed that a minimum of two inches of asphalt pavement would be required when laid over a concrete base. As mentioned in Section A.1.11, data in Means' Building Construction Cost Data 1982 show that doubling the pavement thickness results in doubling the cost per square meter and halving the coverage rate. The costs and rate for paving over concrete were estimated using this relationship applied to the representative data for paving over asphalt. Therefore, the rate is 1419 square meters per hour and the total cost per square meter is $4.04. This total breaks down into $0.22 for labor, $0.20 for equipment, and $3.62 for material.

A.2.12 Resurface

As with resurfacing asphalt (see Section A.1.12), resurfacing concrete involves planing followed by an application of a thin layer of asphalt. The only differences between resurfacing concrete and asphalt are that planing concrete takes longer than planing asphalt and that a thicker pavement layer is necessary on concrete. Resurfacing as a single operation therefore amounts to combining planing and paving. This is shown in Table A.2.12.1. The rate for

TABLE A.2.12.1. Summary of Concrete Road Resurfacing Data

Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
Plane	625	1.09	0.42	0.67	--
Pave	1419	4.04	0.22	0.20	3.62
Total	1419	5.13	0.64	0.87	3.62

the combined operation is set at that of the more costly step, paving. This means that 1419 ÷ 625 = 2.27 planing crews would be used for every paving crew.

A.2.13 Medium-Thickness Asphalt Overlay

See Section A.1.13.

A.2.14 Removal and Replacement

See Section A.1.14 for a general discussion of removal and replacement of pavement. The data collected and the representative data are shown in Table A.2.14.1.

A.3 ROOFS

The techniques for decontaminating roofs include vacuuming, low-pressure water flushing, high-pressure water flushing, sandblasting, foam, strippable coating, and removal and replacement. Since most of these procedures are not performed on a regular commercial or other basis, the estimates pertaining to them are not as strong as they otherwise would be.

Roofs vary considerably with respect to such aspects as height, slope, construction material, presence or absence of rain gutters, and area. The types of roofs and their setting considered here are usually residential roofs one to two stories high with a slight pitch. Other roof types are also explicitly considered. Note that height may not translate directly into difficulty. Higher roofs are generally built with accomodation for access, either inside or outside the structure. Such roofs may also have fire mains and other features conveniently located.

A.3.1 Vacuuming

Vacuuming has the advantage of removing radioactive particles without causing extensive damage to the surface and without creating a new problem such as a large volume of contaminated water. Two commercial sources, out of several contacted, responded that they do or would vacuum roofs.

American Maintenance Systems in Seattle, Washington performs custodial duties on a contract basis. They said that although they do not regularly vacuum roofs, they could and would if hired to do so. The method would be to supply a worker with an aluminum extension ladder and a portable vacuum of the sort that can be strapped on the back. This equipment costs about $200. In some cases, the worker may be provided with a cannister vacuum with 100 feet of hose. This vacuum could cost from $100 to $500. In general, this procedure has very low equipment requirements. If total initial capital cost per worker is $600 and if the equipment is reasonably durable, then a charge of about $1.50 per hour for capital would be adequate. Figuring labor at $17.45 per hour puts the total hourly cost at $18.95.

This source estimated that a 1,000 square foot roof could be vacuumed in 45 minutes. Adding 15 minutes for moving to the next roof gives an average

TABLE A.2.14.1. Summary of Pavement Removal and Reconstruction Cost and Productivity Data

Source Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
		CONCRETE SURFACES			
Means					
Removal	23	4.66	1.86	2.80	--
Replacement	182	18.93	0.95	3.03	14.95
Total	134	23.59	2.81	5.83	14.95
Englesman					
Removal	69	2.40	1.22	1.18	--
Replacement	160	13.25	0.93	0.53	11.79
Total	144	15.65	2.15	1.71	11.79
Representative					
Removal	46	3.53	1.54	1.99	--
Replacement	171	16.09	0.94	1.78	13.37
Total	171	19.62	2.48	3.77	13.37

rate of 1,000 square feet per hour. With one hour per every eight-hour shift set aside for equipment and personnel radiation decontamination, the estimated total coverage in one shift is 7,000 square feet. Converting to square meters per shift-hour, we get an average production rate of 81 square meters per hour. The average unit cost is:

$$\frac{\$18.95/\text{hr} \times 8 \text{ hrs}}{7{,}000 \text{ ft}^2 \times 0.093 \text{ m}^2/\text{ft}^2} = \$0.23/\text{m}^2$$

Power Master, Inc. in Portland, Oregon, operates large high-power mobile vacuums for contract jobs. This equipment is quite powerful and could be inappropriate for use on some roofs. The rental of the machinery, including operators, is $144.50 per hour. The company is occasionally hired to vacuum roofs. Its charge for doing this is between $10 and $16 per 100 square feet.

Using the average Power Master charge for 100 square feet avoids the necessity of adjusting for nonproductive time because this charge includes compensation for periods without production. These occur because the company carries an inventory of extra equipment to handle load fluctuations, thus, the cost per unit area is

$$\frac{\$13/100 \text{ ft}^2}{100 \text{ ft}^2 \times 0.093 \text{ m}^2/\text{ft}^2} = \$1.40/\text{m}^2.$$

Power Master supplied no information on the rate of surface treatment.

The Power Master cost comes to nearly ten times the American Maintenance figure. This is, of course, directly related to the heavy capital intensity with Power Master's big mobile vacuum. The American Maintenance Systems-based cost estimates seem reasonable, and they are taken.as a representative estimate of the cost of vacuuming roofs. Labor constitutes 92 percent of the costs of this operation, with the remaining eight percent going to equipment.

A.3.2 Low-Pressure Water Flushing

The simplest way to accomplish a low-pressure hosing of roofs is to equip each worker so engaged with two to four sections of garden hose, a spray nozzle and an aluminum extension ladder. The hose would be attached to the structure's existing water mains and operated at standard water pressure. The time to hose a roof would be about the same or slightly faster than the time to vacuum it. Here we assume 45 minutes per 1000 square foot roof, plus 15 minutes to move to the next roof. With seven hours productive work in an eight-hour shift, 7000 square feet or 651 square meters of roof will have been treated. The average hourly production will be 81 square meters.

For this procedure, each worker would be equipped with relatively little capital. Hoses, ladder, and so forth would amount to not more than $200. As a rough approximation, we can budget one dollar per hour for capital, bringing total hourly costs to $18.45. Adjusting for one hour per shift for radiation control, the unit cost is $0.23 per square meter. Labor comprises 95 percent of the costs and equipment five percent.

While this method has good removal efficiency with respect to its cost, the resulting contaminated water could pose a problem. Depending on the conditions, it may be acceptable to allow the water to percolate into the soil, or it may be sufficient to direct the runoff into the storm sewers. In more severe instances, it may be necessary to collect the water using rain gutters and drain spouts, or it may be unwise to use water at all.

A.3.3 High-pressure Water

Water at pressures in the range of 80 to 120 pounds per square inch provide good scouring to remove embedded radioactive particles. However, this pressure is high enough so that it would be possible to cause damage to the roofs. Hosing upward against the lay of shingles could rip them off. For this reason it is generally necessary to direct the stream of water down on the roof. In most cases this requires someone to be on or above the roof.

A relatively simple method to accomplish this task is to use a method similar to that described for low-pressure hosing of roofs. The basic equipment is again hoses, but this time fire hoses capable of delivering water to the nozzle at sufficiently high pressure are used. However, in this case the weight, rigidity, and back pressure on the hose make it unwieldy enough so that two or three people per hose would be required.

Some data on the productivity of hosing roofs has been compiled from actual experience. The Administrative Services Manager of Spokane Community College in Spokane, Washington, directed the cleanup of the campus following the 1980 eruption of Mount St. Helens. That catastrophic event covered all exterior surfaces with a layer of volcanic ash. Roofs were cleaned by firehosing. They found that the average productivity was 7,500 square feet per man-hour. However, this rate was achieved on large, institutional-sized buildings. Not so much time was spent shifting from one roof to another and shifting from one hydrant to another. Further, the data on decontamination efficiency do not indicate the amount of water necessary to achieve the stated removal percentages. In general, one would expect that in terms of actual hosing time, high-pressure hosing would take no longer and might be somewhat faster than low-pressure hosing. On the other hand, moving from one roof to another may take somewhat longer, even with the extra manpower, due to the weight and stiffness of the hose as well as the wider spacing of hydrants.

On the basis of these considerations, we estimate a rate almost identical with that for low-pressure hosing: 40 minutes for a 1,000 square foot roof and 20 minutes to move from roof to roof. The production in an eight-hour shift would be 7,000 square feet after including time for equipment and personnel radiation protection measures. Again, the average coverage per hour would be 81 square meters.

The costs would include those for labor and for equipment. Here we assume three-man crews, giving a labor cost of $58.35 per hour. In addition, there are the costs for a ladder and hose. The length of hose necessary depends on the spacing of the hydrants. If hydrants are placed every other block, then they will be somewhat more than 600 feet apart. This suggests that hosing crews should have sufficient hose to cover everything in a radius of more than 300 feet. We estimate that 500 feet of 1-112-inch hose, ten sections of 50 feet each, should be enough for the average crew. Referring to the costs in Table A.1.3.1, we see that the hose sections, with couplings, will cost $550 in constant 1982 dollars. With nozzle and other miscellaneous fire equipment, the cost will come to about $600. With the ladder, the total will be about $675.

According to the source at Yakima Community College, the hoses wore out after two weeks of continual use. It is not clear if that equipment was in good shape to begin with or if the usage to which it was put was especially hard or easy. Taking the wear factor into consideration, we estimate equipment costs at $2.00 per hour.

Total costs, then, are $60.35 per hour, or $0.74 per square meter. Labor, of course, accounts for nearly all of this cost - 97 percent. Equipment makes up the remaining three percent.

In the event that high pressure water mains are not available, a pumper truck would be necessary to operate the required water pressure. Referring to the additional cost that this equipment entailed for high pressure hosing of pavement, we estimate that the increase in cost for hosing roofs would be about $1.60 per square meter. This figure is based on the hourly cost of the pumper at $130 divided by the coverage rate of 81 square meters per hour.

Other options for high-pressure hosing of roofs include using fire department ladder trucks or mobile man lifts. This equipment would not reduce labor costs but would substantially increase hourly equipment costs. Further, actual hosing time would not be substantially reduced. Therefore, if there is to be a gain by using such equipment, it would have to come from reducing the time it takes to move from one roof to the next, or from a high premium on quick decontamination of roofs.

A.3.4 Sandblasting

The abrasive action of either wet or dry sandblasting can be very effective in removing embedded radioactive particles. However, two factors can severely limit this effectiveness. The first of these has to do with the material being blasted. Blasting tar or composition surfaces can actually drive some of the contamination into the material. This becomes more likely at higher temperatures. The second limitation is that both wet and dry sandblasting tend to spread the radiation to other surfaces. With wet blasting there is the problem of contaminated water and sand. With dry blasting the resultant dust will contaminate other surfaces and recontaminate surfaces just cleaned.

A possible solution to this is vacuum blasting. The dry sandblasting nozzle is surrounded by a cone which is attached to a vacuum. The result is that the dust and sand created by the blasting is immediately vacuumed away. The drawback is that the vacuum greatly weakens the blasting action and the amount of blasted sand has to be reduced. Vacuum blasters cover a strip about 0.75 inches wide. Daily coverage of 40 to 50 square feet per day is considered quite good. The result is that it is generally less costly to replace the roof than to vacuum blast it. This and the following information come from Oliver B. Cannon & Son of Richland, Washington. This firm has experience at the Hanford Nuclear Reservation in sandblasting for radiation cleanup.

The basic equipment required for sandblasting includes a truck with an air pump with a capacity of 185 to 200 cubic feet of air per minute, a two hundred pound pot of sand, two 100-foot hoses with nozzles, and miscellaneous equipment including hoods and so forth for the two-man crew.

Normal daily production when done on a continuous basis is 2000 square feet in eight hours. If the average roof is about 1000 square feet in area, and it takes 20 minutes to shift from one roof to the next, then it will take a total of eight hours and 40 minutes to blast 2000 square feet. Converting to square meters per hour and adjusting for one hour per shift for radiation control measures this operation can be done as follows:

$$\frac{2000 \text{ ft}^2}{8\frac{2}{3} \text{ hrs}} \times 0.0929 \times \frac{7}{8} = 19 \text{ m}^2/\text{hr}$$

The cost for dry blasting runs about $0.20 to $0.30 per square foot for light application. Using a figure of $0.35 per square foot for a heavier application, and adjusting the cost upward to account for one hour per shift lost to equipment and personnel radiation protection measures, we get a cost of $0.40 per square foot, which equals $4.30 per square meter. Wet blasting costs 10 to 15 percent more than dry blasting. Using an average 12.5 percent increase, the cost per square meter for wet blasting is $4.84 per square meter. Neither of these cost figures includes any allowance for dust control or water treatment.

The wet blast cost is taken as representative since this method is more likely to be used. Blasting from the top down on a sloped roof will leave the roof decontaminated, and the water and sand by-product can be left on the ground to allow the radiation to leach into the soil or may be picked up by another method.

The cost shares may be approximated in the following way. The cost per shift for sandblasting varies from about $400 to $800 per shift depending on whether it is wet or dry blasting and depending on whether a light or more thorough coverage is achieved. Labor cost for the two workers will be somewhat higher than the assumed base wage rate of $17.45 due to the special equipment operating skills required. If we assume a labor cost of $20 per worker, labor's share of the cost is somewhere in the range of five to ten percent. The latter figure seems more consistent with others derived, so it is taken as representative. Remaining costs are for equipment.

A.3.5 Fixative

Like several other operations, application of a fixative involves spraying the surface with some chemical mixture using paint spraying or similar equipment. The estimation of the cost for such an application procedure to roofs is discussed in Section A.3.7. Fixatives and their characteristics are explained in Section A.7.1. Of the fixatives discussed, Compound SP-301 appears to be an appropriate choice for use on roofs.

If it is not necessary to strictly confine the applied fixative to the roof surface, it can be applied with a device such as a hydroseeder. This is a mobile tank truck equipped to spray liquids to areas adjacent to roads. It is typically used by highway departments for seeding areas next to roads and for other liquid treatments of roadside surfaces. According to the Washington State Department of Transportation, a hydroseeder has the capability of covering an acre per hour with the required coating of 0.4 gallons per square yard. This works out to a 32 gallon per minute pump rate. A hydroseeder might be used to apply fixative to roofs if lawns are to be coated with fixative and if building sides are to be replaced. The estimated cost of application by this method, excluding the cost of the fixative, is $1.19 per square meter, the same cost as applying fixative to lawns. The calculations for this cost estimate are explained in Section A.4.5.

It is more likely, however, that a carefully confined application of fixative will be required. This could be accomplished using mobile sprayers of the sort described for the application of foam and strippable coating of roofs. Minor modifications probably would be necessary so that a non-aerosol spray could be used, though this should not have any significant impact on the estimated costs of this method of application. Therefore, the previously estimated cost of $0.99 per square meter for application will be used in this case, as well. To this must be added the cost of the fixative which was calculated elsewhere at $0.23 per square meter. This brings the total cost of applying fixative to $1.22 per square meter. Again, this operation requires two workers and a spray truck with miscellaneous equipment such as ladders, hoses, and so forth.

A.3.6 Foam

The basics of foam decontamination technology were described in Section A.1.5. In that section, the cost per square meter for chemicals was calculated as $0.083. To this cost need to be added the costs of application and removal.

Mobile sprayers of the sort used for commercial lawn, shrub, and tree spraying or paint sprayers appear to have the capability to apply decontamination foam. Acording to commercial lawn spraying services such as A-Z Pest Control in Richland, Washington, and Roger's Spray and Tree Service in Seattle, Washington, these trucks have a capacity of around 300 gallons and the ability to deliver an aerosol spray at the rate of 32 gallons per minute.

A-Z Pest Control's normal charges are about $80 per hour for labor and equipment. With two workers per truck, equipment accounts for about $45, or 56 percent of the total. However, the source added that the hourly charge would probably be lower if they could operate on a continuous basis. Therefore, this figure should be adequate for any equipment modifications that might be required.

Assuming 45 minutes per 1,000 square foot roof and 15 minutes to move from one roof to the next, the average daily production during seven out of eight hours would be 7,000 square feet. This works out to 81 square meters per hour. The cost of application per square meter, including labor is, then:

$$\frac{\$45/hr + \$35/hr}{81\ m^2/hr} = \$0.99/m^2$$

The cost of labor per square meter is

$$\frac{\$35/hr}{81\ m^2/hr} = \$0.43/m^2$$

The cost of equipment as calculated similarly is

$$\frac{\$45/hr}{81\ m^2/hr} = \$0.56/m^2$$

Removal of the foam would require a large-capacity vacuum. The solution here seems to be to fit a fairly long extension onto the hose intake of a mobile vacuumized street sweeper. We assume the same vacuuming production rate here as estimated for vacuuming roofs without foam - 81 square meters per hour. As for the cost of this vacuuming, we first convert the representative total cost of mobile street vacuuming to a cost per hour.

$$8,777\ m^2/hr \times \$0.0043/m^2 = \$37.74/hr$$

Then this amount is divided by the average hourly area vacuumed to give the cost per unit area:

$$\frac{\$37.74/hr}{81\ m^2/hr} = \$0.47/m^2$$

To this we add the cost of an additional worker at $17.45 per hour:

$$\frac{\$17.45/hr}{81\ m^2/hr} = \$0.215/m^2$$

To find the total cost of the foam treatment to roofs, we add the costs of the separate parts. This brings the total to $1.54 per square meter. These data are summarized in Table A.3.6.1.

TABLE A.3.6.1. Summary of Cost and Productivity Data for Foam Decontamination of Roofs

Item	Rate (m^2/hr)	Cost (1982 $/m^2) Total	Labor	Equipment	Materials
Chemicals	---	0.08	---	---	0.08
Application	81	0.99	0.43	0.56	---
Removal	81	0.66	0.43	0.23	---
Total	81	1.73	0.86	0.79	0.08

A.3.7 Strippable Coating

The essentials of strippable coating as a decontamination method were described in Section A.1.6. The cost for using this technique on roofs is calculated much as the costs for foam decontamination were calculated in the previous section.

In Section A.1.6, the cost of the chemici for strippable coating was estimated at $1.77 per square meter. To this amount must be added the costs of application and removal. Again, a modified mobile landscape spray truck or paint spraying equipment, as was suggested for application of foam to roofs, could be used for applying strippable coating as well. The pump and nozzle apparatus would have to be modified to produce a non-aerosol spray, but even with these modifications a charge of $45 per hour for equipment should be adequate. With two workers the total cost of application would be $80 per hour and $0.99 per square meter.

The cost of removing the coating is hard to estimate without some data on that sort of operation. It is not clear if in pulling the coating up, shingles would come loose. According to a source at Turco Products, this material is very easy to remove and removal can be done quickly, but such a description must be tempered with the caveat that there is little or no experience in this operation.

Removing the strippable coating from roofs would be basically a hand operation. A worker would use a knife to make sufficient cuts in the film so that it could be pulled off easily. The sheets of coating would be thrown on the ground for later pickup and disposal. We assume two man-hours to strip a roof and move to the next one - about twice as long as to vacuum it. In addition, we estimate ten minutes of pickup-truck (or other small or medium truck) time per roof to load the stripped coating which had been thrown on the ground.

Using the base labor charge, the cost of labor per shift for stripping would be $140. To this we add the cost of incidental equipment such as knife and ladder. One dollar per hour would cover this, so the shift total for incidental capital would be $8 and the shift total for removing the coating would be $148. Assuming 3.5 roofs, or 3,500 square feet, stripped per shift, the average hourly coverage is 41 square meters. The unit cost is:

$$\frac{\$148/\text{shift}}{3{,}500\ \text{ft}^2/\text{shift} \times .093\ \text{m}^2/\text{ft}^2} = \$0.45/\text{m}^2$$

Almost all of this cost - 95 percent - is for labor. Only 5 percent is for equipment.

Disposal of the removed strippable coating would be handled in two steps. Pickup trucks would collect the strippable coating from the sites where the coating was used and transport the material to a central collection point where larger trucks would be loaded for hauling to the final disposal site. In this way, the more costly larger trucks could be used more effectively through quicker loading. For strippable coating, it may be desirable to use garbage trucks with hydraulic compression equipment to reduce the volume of material. If these trucks were used, the pickup trucks would not be necessary.

The cost of a pickup is estimated from Means' Building Construction Cost Data for 1981. The monthly rental cost is listed at $275, and the hourly operating cost is $3.94. Adding the cost of the driver and assuming 43 shifts per month, the cost per shift for the truck and driver is:

$$\frac{\$275/\text{mo}}{43\ \text{shifts/mo}} + (\$3.94/\text{hr} + \$17.45/\text{hr}) \times 8\ \text{hrs/shift} = \$177.52/\text{shift}$$

Assuming ten minutes of truck time per roof, the coverage during a shift is 3,906 square meters. The hourly average is 488. The cost per square meter is:

$$\frac{\$177.52/\text{shift}}{3906\ \text{m}^2/\text{shift}} = \$0.05/\text{m}^2$$

Labor comprises 79 percent of the cost of this suboperation. The costs of operation and ownership of the pickup truck make up the remaining 21 percent.

The foregoing information is compiled in Table A.3.7.1. It is clear that chemicals comprise a major part of the overall cost. One implication of this is that crude bulk application techniques, such as hosing the roof with strippable coating from the ground, are probably not cost effective. While there would be savings in per-unit labor costs due to the faster rate of application, such a method would likely result in a significant increase in the overall amount of chemical solution required since a larger portion of it would miss its target. Also, the inability to control thickness as accurately would probably necessitate a higher average volume of coating solution per unit area to assure that minimum thickness requirements were met.

The various steps comprising this operation were combined such that the rate of each was equal to the most costly. Here the most costly step is application with a rate of 81 square meters per hour. Removal would require

TABLE A.3.7.1. Summary of Cost and Productivity Data for Decontamination of Roofs Using Strippable Coating

Item	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
Chemicals	---	1.77	---	---	1.77
Application	81	0.99	0.43	0.56	---
Removal	41	0.45	0.43	0.02	---
Pickup	488	0.05	0.04	0.01	---
Total	81	3.26	0.91	0.58	1.77

nearly two (81/41 = 1.98) removal crews per application crew. Pickup would require only 81/488 = 0.166 crew per application crew.

A.3.8 Removal and Replacement

The most effective technique for removing radioactive contaminants on roofs is, of course, to remove the whole roof and replace the roof surface with a new one. However, removal should be preceded by fixing the contamination to the roof to prevent roof removal activities from inadvertently spreading radioactive particulates on surrounding pavement and lawns (see Section A.3.6).

The costs of the actual removal and replacement were taken from Means Building Construction Cost Data, 1982. In addition, a source at the American Institute of Architects in Washington, D.C., referred to Means to get estimates for roof removal and replacement. This source lists the costs of removal for just one type of roof material, even though costs for installation of several roof types were given. For this reason the cost data reported here refer to five-ply, built-up tar and gravel construction. The major cost difference between this material and others is due to materials. Some other roof types, such as asphalt strip shingles, are generally less expensive, while cedar shingle roofs cost about 50 percent more to install than five-ply, built-up roofs.

The cost for removal is listed as $50 per 100 square feet of roof. Labor comprises all of the cost, the crew consisting of one foreman and four building laborers. Means gives the rate as 1600 square feet per day, or 200 square feet per hour. This is equivalent to 16 square meters per hour, as shown in these calculations:

$$1600 \text{ ft}^2\text{/day} \times \frac{7}{8} \text{ adj} \times \frac{1}{8 \text{ hrs/day}} \times 0.0929 \text{ m}^2\text{/ft}^2 = 16 \text{ m}^2\text{/hr}$$

At 200 square feet per hour and $50 per 100 square feet, the hourly cost is $100. The cost per square meter is then found by dividing the hourly cost by the hourly coverage.

Again following Means, roof replacement requires a crew of one roofing foreman with an hourly billing cost of $27.25, four roofers at $24.25, and two roofer helpers at $18.30. The total hourly labor cost is $160.85. In addition, miscellaneous equipment comes to $10.18 per hour.

The total hourly cost is equal to the hourly rate (300 square feet) times the cost per square foot ($1.10) : $330 per hour. Subtracting the labor and equipment costs from the total cost gives the hourly material cost at $158.97. Since the material cost is not subject to any productivity adjustment, it can be converted directly to a cost per square meter in the following manner:

$$\frac{\$158.97/hr}{300\ ft^2/hr \times 0.0929\ m^2/ft^2} = \$5.70/m^2$$

The adjusted production rate is

$$300\ ft^2/hr \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 24\ m^2/hr$$

Dividing the hourly labor and equipment costs by the adjusted hourly coverage yields the labor cost per square meter ($6.70) and the equipment cost per square meter ($0.43). The total cost per square meter ($12.83) is found by adding the costs for the three input categories.

Table A.3.8.1 summarizes the results of these calculations and shows the total cost for removal and replacement. As previously, the more costly procedure determines the overall rate. Therefore, 24/16 = 1.5 roof removal crews for every roof replacement crew would be required to maintain the rate of 24 square meters per hour.

TABLE A.3.8.1. Summary of Roof Removal and Replacement Cost Data

Procedure	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Materials
Roof Removal	16	6.25	6.25	--	--
Roof Replacement	24	12.83	6.70	0.43	5.70
Total	24	19.08	12.95	0.43	5.70

A.4 LAWNS

Lawns present particular difficulties for decontamination, largely as a result of the surface texture. There are three general ways to remove radiation from lawns. The first is to lift the material out of the lawn by vacuuming or close mowing. The second is to drive the contaminants down below the surface by watering or using a chemical leaching agent. The third is to remove the radioactive particles by removing the whole lawn and replacing it with a new lawn. These approaches are discussed below.

A.4.1 Vacuuming

There are a variety of ways in which lawns could be vacuumed. These include using standard home vacuums, using portable vacuums which can be strapped on one's back, using the large push-type vacuums which are often used for parking lot cleanup, using standard mobile vacuumized street sweepers, or using the very high-powered, truck-mounted vacuums described in Section A.3.1. Comparative decontamination efficiency data are not available to guide the choice of equipment. However, from the information available, it would seem that the Power-Master type truck-mounted vacuum would be too powerful for this job, while home vacuums and back-carried vacuums are too small and lack sufficient power for this sort of work. Because of capacity, power, and mobility, we assumed that vacuumized street sweepers, using existing hose intakes fitted with several feet of hose and an intake nozzle, would be the best option for this operation.

Referring to the vacuumized street sweeping data presented in Table A.1.1.9, we can calculate the cost per hour of operating this equipment by multiplying the cost per square meter by the number of square meters per hour. Doing this gives an hourly labor cost of about $18.00 for labor and $19 for equipment for a total of $37.00 per hour. This operation would require an extra worker per truck which is estimated at $24.95 per hour, the Means billing cost for a medium equipment operator. This raises the total hourly labor cost to $43.00. Additional equipment including hoses and fittings should add about $1.00 per hour to equipment charges, raising total equipment charges to $20.00 per hour. The total hourly cost is, then, $63.00 per hour.

We assume an average of 4000 square feet of lawn per house and a productivity rate of 4000 square feet of lawn vacuumed per hour. Adjusting this figure for one hour in eight being lost to non-productive radiation-control measures and lower productivity brings the average hourly coverage to 3500 square feet, or 326 square meters. Dividing this into the cost per hour yields $0.19 per square meter. The inputs' respective shares of total cost are $0.13 per square meter for labor and $0.06 per square meter for non-labor inputs. Since vacuuming lawns involves less vehicle movement than vacuuming streets, fuel costs may be somewhat lower than in street sweeping operations.

A.4.2 Water

Under some conditions, driving radiation into the soil may be an acceptable method of mitigating the radiation hazard. One way this can be accomplished is by watering the lawn. This strategy will be more attractive when there is no important underground water source which might be contaminated and when it is unlikely that the radioactive material will travel a significant distance through the soil.

The simplest and most economical way to accomplish this is for a worker to move from house to house, turning on existing sprinklers. For houses without a sprinkler system, the worker would set up hoses with ordinary lawn sprinklers attached. Any necessary watering equipment could be dropped from a large pickup or stakebed truck at various intervals along streets. After this initial equipment distribution, the hoses and so forth would probably be most efficiently moved without any motor vehicles. After setting up the water sprinkling equipment on one lawn, the water would be left running while the person moved to the next lawn. This would continue until enough time had passed so that a sufficient amount of water had been applied to the first lawn. The person would return to that lawn, shut off the water, and move any equipment to the next unwatered lawn.

For an operation such as this, there is no information based on experience. Unit cost and rate estimates are based on assumption. The hourly labor cost used is $17.45., the billing cost for common building laborers as reported in Means' Building Construction Cost Data 1981. To this is added $1.50 per hour for equipment. For a lawn of 4000 square feet, we estimate 15 minutes of labor time. This is an average, considering that for some lawns all that will be necessary would be to turn the existing sprinkler system on and off. For other lawns it will be necessary to bring sprinkler equipment, set it up, turn it on, and remove it after turning it off. Using this estimate, we have a cost per shift of:

$$8 \text{ hr/shft} \times (17.45/\text{hr} + 1.50/\text{hr}) = \$151.60/\text{shift}$$

Since there will be only seven productive hours during the eight shift hours, total coverage during a shift will be seven times the average hourly coverage of 16,000 square feet. This works out to 10,416 square meters per shift, or 1302 square meters per shift hour. The cost per unit area is

$$\frac{\$151.60/\text{shift}}{10{,}416\ \text{m}^2/\text{shift}} = \$0.014/\text{m}^2$$

This method is obviously very labor intensive. Labor comprises 92 percent of the cost ($0.013 per square meter).

A.4.3 Leaching

The action of moving the contaminants down into the soil with water can be greatly accelerated by the use of any of a number of chemical leaching agents such as ferric chloride ($FeCl_3$), EDTA (ethylenidiaminetetraacetic acid), or calcium chloride. These have the ability to solubilize contamination particles so that they are more readily carried down into the soil.

The most efficient way to handle treatment of lawns with water and leaching agents such as ferric chloride seems to be to apply a concentrated chemical solution to the lawns from a tanker truck equipped for spraying. This would be followed with a water treatment as described in the previous section (A.4.2). Several sources reported effectiveness data for 0.3-inch application of water with ferric chloride. The original study to which these sources refer used a solution of one-percent ferric chloride by weight (Dick and Balcer 1967). Percentages by weight are about equal to percentage by volume for this material. Presumably precise control of the mixture is not extremely important. The amount of leaching agent used would be determined primarily by the type of soil. Another consideration is whether it is desirable to attempt to limit the depth to which the contaminant is moved.

Ferric chloride is sold in powder form, but more frequently it is sold in a 40-percent aqueous solution. To apply enough of this solution so that there would be sufficient ferric chloride for a one-percent solution of 0.3-inch total coverage, one gallon of the 40-percent solution should be applied to every 21 square feet. This was calculated in the following way:

$$\frac{231\ in^3/gal \times 0.40\ \text{fraction}\ FeCl_3}{0.01\ \text{fraction}\ FeCl_3\ \text{desired} \times 0.3\ in\ \text{coverage}}$$

$$= \frac{92.4\ in^3\ FeCl_3/gal}{0.003\ in\ FeCl_3\ \text{coverage desired}}$$

$$= 30{,}800\ in^2\ \text{covered}\ 0.003\ in\ \text{deep with}\ FeCl_3/gal$$

$$\frac{30{,}800\ in^2\ \text{covered}/gal}{144\ in^2/ft^2} = 213.9\ ft^2\ \text{covered}/gal$$

$$213.9\ ft^2/gal \times 0.093\ m^2/ft^2 = 19\ m^2\ \text{covered}/gal$$

Various sellers of ferric chloride were contacted. The prices for a ton of ferric chloride on a 100 percent basis for large volume shipments are shown in Table A.4.3.1. Prices differ largely because of volume, packaging, and shipping factors. On the basis of these figures, we used a price of $200 per

TABLE A.4.3.1. Prices of Ferric Chloride by Various Suppliers for Large Volume Shipments

Supplier	Price (1982 $/ton)
Conservation Chemical	200
DuPont, Chemicals, Dyes & Pigments Dept.	176
C.P. Hall	260
Chemwest	200

ton of ferric chloride. This is equivalent to $0.10 per pound. Further, Conservation Chemical and C.P. Hall reported that a 55 gallon drum of 40 percent solution weighs 600 lbs. Thus, a gallon weighs about 11 pounds which means there are about 4.4 pounds of material per gallon; therefore, the cost is about $0.44 per gallon.

Including an allowance for shipping and so forth brings the cost to about $0.50 per gallon. The cost of ferric chloride per square meter is:

$$\frac{\$0.50/\text{gal}}{19\text{m}^2/\text{gal}} = \$0.0263/\text{m}^2$$

A hydroseeder, as described by a source with the Washington State Department of Transportation, would provide an effective means of applying the concentrated leaching agent solution. This machinery can easily spray surfaces within a radius of 100 feet. The reported average coverage rate of this equipment is in excess of an acre per hour at 0.4 gallons per square yard. This is equivalent to an average pumping rate of 32 gallons per minute. These figures include time for refilling. It is possible that metal surfaces on the hydroseeder may have to be coated to prevent corrosive action of the leaching agent.

The Washington State Department of Transportation reported that the hydroseeder entails a labor cost of $60 per hour for two workers plus $135 per hour for the equipment. The application rate of one gallon for 19 square meters is probably too thin to be done with much uniformity of coverage. Therefore, we assume that the solution is partially diluted before applying. If the ferric chloride is diluted, say, four parts water to one part of the solution as purchased, then one gallon of this mixture should be applied over an area of about 3.8 square meters. The pump rate of 32 gallons per minute for the hydroseeder multiplied by the coverage of 3.8 square meters per gallon gives an output of 122 square meters per minute. Coverage per shift-hour would be

$$122\ \text{m}^2/\text{min} \times 60\ \text{min/hr} \times 7/8\ \text{adj} = 6400\ \text{m}^2/\text{hr}$$

Dividing this into the hourly costs gives $0.009 per square meter for labor, $0.021 for equipment. The total cost of operating the hydroseeder apart from the leaching agent is $0.03 per square meter.

The costs of applying the water are explained in the previous section.

Table A.4.3.2 summarizes the cost of leaching. Combining the different procedures so that the overall rate equals the rate of the most costly step requires that 4.92 watering crews be used for every application crew.

TABLE A.4.3.2. Summary of Leaching Cost and Productivity Data

Item	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
Ferric Chloride	--	0.026	--	--	0.026
Application of Chemicals	6400	0.030	0.009	0.021	--
Watering	1302	0.014	0.013	0.001	--
Total	6400	0.07	0.022	0.022	0.026

A.4.4 Close Mowing

Close mowing of contaminated lawns is another method of reducing the radiation hazard from that surface. Because the total lawn surface will be broken down into numerous small, odd-sized parts, and because some lawns will have only limited access, large mowers would be too cumbersome for efficient use. Smaller riding mowers seem to be the most attractive option. Besides mowing, the workers must also see that lawn cuttings are carefully bagged for later removal. Mowers with a vertical axis cutting blade would be used since they would pick up particles with a vacuum action.

Three sources supplied cost and rate estimates for this operation. Since the equipment specifications did not change much from source to source, the major areas of difference were in wage rates and productivity rates. An allocation of about $2.00 per hour appears to be adequate to cover the costs of the mower, maintenance, and fuel. We estimate that 15 minutes of time for labor and a pickup truck is sufficient for pickup and disposal of bagged clippings.

According to Means' Building Construction Cost Data 1982, the monthly rent for a pickup truck is $275, and the hourly operating cost is $4.24. With 336 working hours per month, the hourly cost for the truck is:

$$\frac{\$275/mo}{336\ hrs/mo} + \$4.24/hr = \$5.23/hr$$

Using Means' billing rate cost for a common labor of $17.45, the total hourly cost for the pickup of lawn cuttings is

$$\$5.23 + \$17.45 = \$22.68/hr$$

Based on the estimate of 15 minutes pickup time per 4,000 square foot lawn, total coverage during the seven working hours of an eight hour shift would be 112,000 square feet or 10,416 square meters. Dividing this figure by eight hours per shift gives the average coverage per shift hour as 1,302 square meters. The cost per square meter can be calculated by dividing the cost per hour by the coverage per hour:

$$\frac{\$22.68/hr}{1302\ m^2/hr} = \$0.017/m^2$$

The Administrative Services Department of the Spokane Community College in Spokane, Washington said that for large, flat, unobstructed areas a large mower such as a Toro Lawn Master with a 4.5 foot mowing width can mow one acre in 15 minutes. However, using a small riding mower for mowing the front and back lawns of a standard 50 foot width lot, this source estimates that 45 minutes are required. To this should be added time for bagging the clippings. This translates into about one hour for 4,000 square feet, or 372 square meters. With an hour per shift lost to special protective measures necessitated by the radioactivity, the average hourly production would be 718 of this amount--326 square meters per hour.

Using Means' common laborer billing rate of $17.45 per hour for the labor cost, the total hourly cost would be $19.45 when the equipment cost is included. The cost per square meter is:

$$\frac{\$19.45/hr}{326m^2/hr} = \$0.060/m^2$$

Labor would account for:

$$\frac{\$17.45}{326\ m^2/hr} = \$0.054/m^2$$

American Maintenance Systems in Seattle, Washington, provided a similar estimate - 45 minutes to an hour to mow 4,500 square feet. Adding the time for bagging, this comes to an hour and fifteen minutes. Adjusting for an average of one hour per shift lost due to the special conditions of working in a contaminated environment, gives

$$\frac{4500\ ft^2}{1.25\ hr} \times 0.093\ m^2/ft^2 \times 7/8 = 293\ m^2/hr$$

Again, using $17.45 per hour for labor and $2.00 per hour for capital and dividing by the hourly production yields a cost per square meter of $0.0664.

The Craft and Operation Services Department of Battelle Pacific Northwest Laboratories in Richland, Washington estimated 10 to 12 hours for 20,000 square feet. This is much slower than the other estimates in part because specific consideration was given to time necessary for the bagging of cuttings and for the slower mowing rate necessitated by cutting the grass as close to the ground as possible. Using a time of 11 hours for 20,000 square feet, the production during an average hour of mowing would be

$$\frac{20{,}000\ ft^2}{11\ hrs} \times 0.093m^2/ft^2 = 169m^2/hr$$

Adjusting this figure for an hour lost per shift for reasons connected with working in a contaminated area, the average hourly production becomes

$$169m^2/hr \times \frac{7}{8} = 148m^2/hr$$

With a labor cost of $20.00 per hour plus $2.00 per hour for equipment, the average cost per square meter is

$$\frac{\$22.00/hr}{148m^2/hr} = \$0.1486/m^2$$

Table A.4.4.1 presents the foregoing data. It is clear that the cost estimate for mowing from Battelle is much higher than the estimates from the other two sources. The reason for this is the explicit consideration given by the source at Battelle for the special actions which must be taken in this case: mowing as close to the ground as possible and careful bagging of the cuttings. Because of these explicit considerations, the representative figures for this procedure are taken as very close to the Battelle figures.

The total cost for the whole operation is the sum of the mowing cost plus the removal cost - $0.147 per square meter. The overall rate is geared to mowing, the more costly step. This means that 150 ÷ 1302 = 0.115 pickup crews would be required for every mowing crew.

TABLE A.4.4.1. Summary of Cost and Productivity Data for Close Mowing of Lawns

Item and Source	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment
Mowing				
Spokane Comm. Coll.	326	0.060	0.054	0.006
Amer. Maint. Sys.	293	0.066	0.059	0.007
Battelle PNL	148	0.149	0.136	0.013
Pickup				
Means	1302	0.017	0.013	0.004
Representative				
Mowing	150	0.130	0.116	0.014
Pickup	1302	0.017	0.013	0.004
Total	150	0.147	0.129	0.018

A.4.5 Fixative

A sticky, penetrating type of fixative might be the most appropriate for use on lawns, though hydrophillic and solid membrane types could also be used. According to the Washington State Department of Transportation, the first step of coating the lawn surfaces with a fixative could be done with a hydroseeder. This is a tanker truck equipped to spray liquids of varying viscosity to surfaces within a 100 foot radius. With a coverage of, say, 0.4 gallons per square yard, this equipment can deliver liquids at a rate sufficient to cover an acre per hour. This implies a pumping capacity of 32 gallons per minute. The hydroseeder requires two workers - a driver and someone to operate the spraying mechanism. The reported cost of operating the hydroseeder is $60 per hour for the two workers plus $135 for the equipment. The equipment charge includes allowance for capital, depreciation, maintenance, fuel, and so forth. These costs work out to a total of $1560 per shift.

The hydroseeder's coverage rate of an acre per hour is equivalent to 4,051 square meters per productive hour. During the seven productive hours of a shift, the total production would be 28,357 square meters. Thus, the unit cost would be

$$\frac{\$1560/\text{shift}}{28{,}357\text{m}^2/\text{shift}} = 0.055/\text{m}^2$$

Labor's share of the cost is

$$\frac{\$60/\text{hr} \times 8 \text{ hrs}}{28{,}357 \ \text{m}^2/\text{day}} = \$0.017/\text{m}^2$$

or $0.017 per square meter. Equipment accounts for the remaining $0.038 per square meter. The average production per shift-hour is

$$\frac{28{,}357\text{m}^2/\text{shift}}{8 \text{ hrs/shift}} = 3{,}545\text{m}^2/\text{hr}.$$

Referring to Section A.7.1, the cost of a fixative appropriate for use on lawns covers a broad range. Here we assume that a fixative like road oil would be used with a unit cost of $0.31 per square meter. This brings the total cost of fixative and application to $0.365. Table A.4.5.1 summarizes the cost and

TABLE A.4.5.1. Summary of Cost and Productivity Data for Applying Fixative to Lawns

Item	Rpte (m /hr)	Cost (1982 $/m²)			
		Total	Labor	Equipment	Material
Fixative	--	0.310	--	--	0.310
Application	3545	0.055	0.017	0.038	--
Total	3545	0.365	0.017	0.038	0.310

productivity data for the application of a fixative to lawns. It is clear that selection of a lower cost fixative would have a significant impact on the total cost.

A.4.6 Removal and Replacement

A relatively effective but costly method of reducing radiation contamination in lawns is to take the direct approach of removing the lawn and replacing it with new sod. To be sure that the radioactive matter is fixed to the lawn to be removed, removal should be preceded by application of a fixative. That step is not included in removal and replacement as described here.

Sod removal and replacement are normally done by the same business and, therefore, the cost is frequently given for the combined procedure. A source at the American Institute of Architects provided a cost estimate of $4.12 per square yard for removal and replacement of sod on flat terrain and $4.53 on a slope. These are figures for the East Coast which should be higher than the national average. Apparently, these data were taken from a Means construction cost publication. Using the average of the figures for level and sloped surface, the cost can be converted to a cost per square meter basis. The following shows this calculation and adjusts for one hour per shift with no production:

$$\frac{\$4.12/yd^2 + \$4.53/yd^2}{2} \times 0.8361\ m^2 yd^2 \times 8/7 = \$4.13/m^2$$

C&M Landscaping of Richland, Washington, charges $0.50 per square foot for lawn removal and replacement. This can be converted to a cost per shift-hour in the following way:

$$\frac{\$0.50/ft^2}{0.093 m^2/ft^2} \times 8/7 = \$6.14/m^2$$

Means' Building Construction Cost Data 1982 (p. 56) indicates that the crew for sodding requires one outside foreman ($22.25 per hour billing cost), four building laborers ($19.40) and one light-equipment operator ($23.70). The total hourly labor cost is $123.55. Necessary earthwork equipment has an hourly cost of $19.86. The total hourly cost on level ground is

$$470\ yd^2/day \div 8\ hrs/day \times \$3.98/yd^2 = \$233.83$$

Subtracting the hourly labor and equipment costs gives the hourly material cost, which can be converted to a dollars-per-square-meter basis with the following calculations:

$$\$(233.83 - (123.55 + 19.86)) = \$90.42/hr \text{ for material}$$

$$\frac{\$90.42/hr}{58.75\ yd^2/hr \times 0.836\ m^2/yd^2} = \$1.84/m^2$$

The rate given for sodding on level ground is 470 square yards per day, and the rate for slopes is 405 square yards per day. We base our calculations on the average of these two rates - 438 square yards per day. Converting to square meters and accounting for one hour per day lost to radiation control measures, we have:

$$438\ yd^2/day \div 8\ hrs/day \times 7/8\ adj \times 0.836\ m^2/yd^2 = 40\ m^2/hr$$

Dividing the hourly coverage rate into labor and equipment costs gives those costs on a dollars-per-square-meter basis:

Labor: $$\frac{\$123.55/hr}{40\ m^2/hr} = \$3.09/m^2$$

Equipment: $\frac{\$19.86/hr}{40\ m^2/hr} = \$0.50/m^2$

Adding the labor, equipment, and material cost gives the total cost as $5.43 per square meter.

The costs given here are different from those given by the American Institute of Architects (AIA), despite the fact that the AIA stated that its source was a Means publication. It appears that the AIA may have used an earlier edition.

Partial information was also supplied by Elite Sod Farm, Richland, Washington. The cost of laying new sod near this business was $0.16 to $0.22 per square foot. This does not include removal of existing lawn. These costs are equivalent to $1.72 to $2.36 per square meter without adjustment for the special radiation measures affecting costs and production rates. Averaging these two amounts together and adjusting for an hour per shift lost due to special conditions imposed by radiation, we get $2.33 per square meter.

Table A.4.6.1 presents the foregoing information. The various costs for removing and installing sod, while not in perfect agreement, seem to be mutually consistent. The representative cost was taken as the Means data.

TABLE A.4.6.1. Summary of Cost and Productivity Data for Removing and Replacing Lawns

Source and Item	Rate ($/m^2)	Cost (1982 $/m^2) Total	Labor	Equipment	Material
Amer. Inst of Archs					
Remove and resod	--	4.13	--	--	--
C & M Landscaping					
Remove and resod	--	6.14	--	--	--
Means					
Remove and resod	40	5.43	3.09	0.50	1.84
Elite Sod Farm					
Resod Only	--	2.33	--	--	--
Representative	40	5.43	3.09	0.50	1.84

A.5 AGRICULTURAL FIELDS

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

A.5.1 Low-Pressure Water

There are several ways in which water could be applied to a field. The simplest would be to use an existing irrigation system, should one be present. However, since many fields--especially those for raising grain--are not irrigated, the cost of applying water was estimated for application using a tank truck with spreader or spray capability. Data used included that for applying water to paved surfaces (see Section A.1.2). This was adjusted to account for the slower rate of application resulting from driving on soft dirt rather than pavement, and also for a longer time to refill the tank. The slower vehicle speed has a relatively small effect on cost, however, since vehicle speed must be slow in either case in order to apply sufficient water. The most important factor affecting cost is the time required to refill the tankers. Where water sources are not available nearby, the cost will be much greater.

In Section A.1.3, equipment for applying high-pressure water to pavement was described. This consisted of a tank truck equipped with a pump and a laterally mounted ten-foot spray bar. Similar equipment could be used for applying water to agricultural fields, though it would not be necessary to apply the water at high pressure. Another alternative is to use a water distributor truck as is used in road construction. These sorts of equipment configurations should not have significantly different costs.

Here, following the discussion in A.1.3, we use an hourly labor cost of $19.75 and an hourly equipment cost of $27.37. This gives a total cost of $47.12 per hour.

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

The rate is, therefore:

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

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

A.5.2 Fixative

Fixatives and their characteristics are described in Section A.7.1. No single fixative is clearly superior for all instances in which a fixative might be applied to agricultural fields. Here we use Coherex as the fixative. This has a cost of $0.19 per square meter when applied using a 1:5 mixture with water.

The equipment to apply the fixative is basically the same as that described in Section A.1.3 for applying high-pressure water to pavement. Here, high pressure is neither necessary nor desired. Further, it is not necessary to apply as much volume of material per square meter as with the water treatment. Therefore, the spray truck can move forward at a somewhat faster rate. In this case a vehicle speed of 1.36 miles per hour is appropriate when the pump rate is 100 gallons per minute and the spray width is ten feet.

A 5000-gallon capacity tank truck will be emptied in 50 minutes with a 100 gallon per minute spray rate. The assumed refill time for water in Section A.1.3 was 30 minutes. Here we raise the assumed refill time to 50 minutes to account for mixing of the fixative with water and the likelihood of a greater travel distance to the refill location. Alternatively, the spray truck could be supplied by "feeder" or "nurse" trucks, though it is not clear that this would result in any cost savings.

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

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

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

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

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

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

A.5.3 Leach

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

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

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

Another leaching agent that might be used is ferric chloride ($FeCl_3$). This is described in Section A.4.3. In that section the cost of applying a one-percent solution was calculated. The cost of the ferric chloride was $0.0263 per square meter. Because of this lower cost, leaching here is assumed to be done with ferric chloride. Another reason for basing these computations on ferric chloride is that there is some test data on the effectiveness of this material used for radiation decontamination.

The same equipment and personnel used to apply water to agricultural fields (see Section A.5.1) would be used for leaching. However, to apply the necessary greater amount of water, a slower vehicle speed would be called for. Experimental data were produced based on an application of 0.30 inches of the water-ferric chloride solution (Dick and Baker 1967). This volume requires a vehicle speed of 0.6 miles per hour. As with fixative application (see Section A.5.2), the application tank truck would be spraying half the time and re-filling half the time. The average coverage per shift-hour would be 1814 square meters. Dividing this result into the hourly labor and equipment costs gives the costs of these inputs on a square-meter basis.

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

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

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

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

A.5.4 Clear

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

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

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

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

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

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

The rate given was 6.52 hours per acre. This converts to

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

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 square meters per hour gives the cost per square meter.

Total: $94.28/ac ÷ 6.52 hrs/ac ÷ 543 m^2/hr = $0.027/$m^2$

Labor: $33.22/ac ÷ 6.52 hrs/ac ÷ 543 m^2/hr = $0.009/$m^2$

Equipment: $61.06/ac ÷ 6.52 hrs/ac ÷ 543 m^2/hr = $0.017/$m^2$

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

A.5.5 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, 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 Excavatins and T.E. Knudson, construction consultant--were also contacted for this report. Additional information was also obtained from the Reynolds Electrical and Engineering Co., Inc., Joseph M. Hans, Jr., and other reports on decontamination procedures. These reports included "Radiological Dose Assessment and the Application and Effectiveness of Protective Actions for Major Property Types Contaminated by a Low-Level Radionuclide Deposition" by Science Applications, Inc., and "Estimate of Potential Costs of Hypothetical Contaminating Events, Subject to 'Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment"' by Battelle-Northwest.

Since scraping is a relatively common operation, there are a variety of techniques and equipment available. For example, the basic scraping equipment could be either a crawler tractor, a bottom-dump scraper, or a grader. While all these seem to be reasonably effective, information from sources experienced in scraping as a decontamination procedure indicated a preference for the grader and front-end loader. The grader scrapes earth into windrows and a front-end loader loads the windrows into dump trucks. This is the principal technique used by the Reynolds Electrical and Engineering Co., Inc., at the Nevada Test Site where they have been engaged in scraping and removing soil contaminated in weapons tests. This source reported that where soil is particularly hard they use a crawler tractor instead. The procedure in this case is for the tractor to drive over the soil first with rear-mounted shallow ripper shanks in a lowered position. After scarifying the soil, the tractor raises the shanks, backs up, lowers the front scoop and proceeds to push the earth into rows or piles. These piles are later picked up by a front-end wheel loader and loaded into a dump truck.

Joseph M. Hans, Jr., of the U.S. Environmental Protection Agency, was involved with the decontamination of a uranium mill site. In this work he gained a familiarity with the effectiveness of earth-moving equipment. He found that common problems include equipment actually driving the contamination below the surface and soil spillage. He reports that equipment needs vary from site to site and that push bottom-dump scrapers were inefficient because they removed too much soil.

In reviewing scraping practices as used in decontamination projects and as used in ordinary earth-moving work, it appears that a grader working with one or more fcont-end loaders in the manner described above constitutes a fairly effective and efficient technique for soil removal.

Those doing decontamination work found that, in addition to the actual scraping, periodic wetting of the soil prevented dust. Application of water was done either with a water wagon or a hydroseeder. Using a hydroseeder to spray water may permit wetting the contaminated soil from a decontaminated area. This reduces disturbances to the contaminated area. Occasionally a small amount of detergent is added to the water to improve wetting.

A final element in the scraping operation is the transporting of contaminated soil to a dump site. The cost of dumping will depend in large part on the distance to the dump site. Some sources envision a dump site for every square kilometer (Julin et al. 1978). At another extreme, soil would be transported to one of the few national nuclear-waste dumps. Such hauls could be over 1,000 miles. Another possibility is that a dump site would be created in or adjacent to any permanently interdicted area.

Relying on Means, an estimate of scraping costs can be developed. The basic piece of equipment is a grader. A 30,000 pound grader costs $51.34 per hour. Operating with the grader are two wheel-mounted front-end loaders, each with a 2.25 cubic yard capacity and each costing $50.79 per hour. The total equipment cost is $152.92 per hour.

The labor requirements are three medium-equipment operators at $24.95 per hour each, one building laborer at $19.40 per hour, and one foreman at $22.25 per hour. The total labor cost comes to $116.50 per hour. Adding the labor and equipment costs together, we get the total hourly cost of $269.42.

The rate is more difficult to estimate. Apparently, the limiting factor is the speed at which the front-end loaders can load the windrows into dump trucks. The front-end loaders are listed as having a 2-1/4 cubic yard capacity with a loading rate of 100 cubic yards per hour. With a scraping depth of about six inches, about five square meters are covered for every cubic yard. Therefore, each front-end loader can cover about 500 square meters per hour. The second loader brings the production rate to 1000 square meters per hour. Adjusting this for the time necessary for personnel and equipment decontamination reduces the rate to 875 square meters per hour. This figure appears to