as one automobile times the scale factor. In the present case a unit is 1,000 autombiles.

The treatment of automobile exteriors includes the cost of towing the automobile to a decontamination facility. There is a $50 charge per automobile for this. The exterior of each car then receives a double wash for an additional $10 per car. Automobile interiors receive a double vacuum for $10 and the tires are sandblasted for another $12.71. Finally, the engine and drive train are cleaned in a solvent for $36.90.

The lower panel in Table 5.9 reports the man-hours and equipment-hours, by type of physical input, required to decontaminate this grid element. Input requirements range from 27,200 hours of medium-equipment operators to just 20 hours of a small tank-spray truck.

5.2.4 Restrictions on Specific Operations

DECON can also be applied to all or part of an area in which certain operations are restricted. In the present study, we demonstrate this feature by prohibiting the use of water while decontaminating exterior surfaces. Contaminated water has the potential of creating major problems. It can penetrate the root systems of plants, crops and trees, and it can contaminate sewage systems and water treatment facilities. The benefits from using water--an inexpensive and effective way to reduce exposure through external and inhalation pathways--must therefore be carefully weighed against the costs.

The results of running DECON with a ban on operations using water are presented in Table 5.10. With a ban on the use of water on exterior surfaces, decontamination costs increase to $344.6 million, from $325 million in the base case. A comparison of the bottom panel in Table 5.10 with the bottom panel in Table 5.7 reveals which surfaces account for the increased costs. For example, in the base case 8,090 square meters of vacant land were treated with water and 25,343 were plowed. With water prohibited, 32,990 square meters are plowed and 529 square meters are not decontaminated.

5.2.5 Required Method

Table 5.11 shows a case in which we pre-specify the method that is to be used on a particular surface. In the present case, we require a single application of water on agricultural fields. Note that even though the decontamination factor for this method is less than the adjusted target decontamination factor, the method is still included because it was required by the user. Although not shown, the method that was previously selected for this surface was plowing followed by a 6" covering of fresh soil. This latter method costs $280,000 versus $5,000 for the less effective watering method.

5.2.6 Varying Exposure Factors

Another application of DECON is to allow the cleanup standards to be adjusted according to the type of surface. The potential usefulness of this feature lies in the fact that human exposures to different surfaces vary

TABLE 5.10 Decontamination Without Water

SUMMARY RESULTS FOR EXPOSURE AREA 1 TO EXPOSURE AREA 14

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

PROBABILITY OF RAIN/SNOW BEFORE DECONTAMINATING	1.0000.	
RADIATION LIMIT FOR ORGAN 1 IS	10.00	
NUMBER OF TIME PERIODS CONSIDERED IS..........	30	
TOTAL DECONTAMINATION COSTS ARE.............. $	344620.	
TOTAL AREA DECONTAMINATED IS.................	507039.0	SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $	.68	
AREA REQUIRING NO DECONTAMINATION IS.........	2079104.0	SQUARE METERS.
AREA THAT COULD NOT RE DECONTAMINATED IS.....	4009.9	SQUARE METERS.
PRE-ACCIDENT PROPERTY VALUE IS .... $	40798520.	
POST-DECONTAMINATION PROPERTY VALUE IS ...... $	367186'70.	
NET PRESENT VALUE OF PROPERTY IS .... $	39998490.	
TOTAL REDUCTION IN PROPERTY VALUE IS .... $	92000'72.	
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS	3325.832	MAN-REM.
SIZE OF RESIDENT POPULATION	2923837.	PERSONS.

TOTAL FACTOR INPUT REQUIREMENTS
(MAN/EQUIPMENT HOURS)

DRIVER, HEAVY TRUCK	423.51
OPERATOR, MED. EQUIPMENT	1700.31
OPERATOR, LIGHT EQUIPMENT	4.13
OPERATOR, FARM EQUIPMENT	23.01
RUILDING LABORER	398.27
COMMON LABORER	258.23
CLEANING WORKER	1036.72
FOREMAN	157.17
PILOT	5.82
FLIGHT CREWMAN	5.82
AIR GROUND CREWMAN	11.63
SPRAY OPERATOR	49.67
FRONT END LOADER	264.42
BULLDOZER	31.71
AIRPLANE	5.82
ORCHARD BLAST SPRAYER	.17
TRACTOR W/PLOW	22.84
CHIPPING MACHINE	71.49
HYDRAULIC EXCAVATOR	67.00
VACUUM, HAND	888.39
PAINT SPRAY EQUIPMENT	49.67
VACUUMIZED STREET SWEEPER	5.69
SANDBLAST EQUIPMENT	.13
TOW TRUCK	12.00
GRADER	85.68
VEHICLE WASHING EQUIPMENT	51.00
DUMP TRUCK	411.51
SMALL TANK--SPRAY TRUCK	1.12
ENGINE STEAM CLEANER	4.00

TABLE 5.10 (cont.)

TOTAL AREA DECONTAMINATED, BY SURFACE AND METHOD

SURFACE TYPE	METHOD	AREA (SQ. METERS)
AGRICULTURAL FIELDS	X	27691.
AGRICULTURAL FIELDS	A	18230.
AGRICULTURAL FIELDS	AG	17408.
AGRICULTURAL FIELDS	NOT DECONTAMINATED	1354.
VACANT LAND	A	32990.
VACANT LAND	NOT DECONTAMINATED	529.
WOODED LAND	TNX	11677.
WOODED LAND	TNx	7334.
WOODED LAND	TDh	965.
WOODED LAND	TX	9093.
WOODED LAND	NOT DECONTAMINATED	570.
EXTERIOR WOOD WALLS	NOT DECONTAMINATED	72.
EXTER'R BRICK WALLS	NOT DECONTAMINATED	144.
LINOLEUM FLOORS	V	12514.
LINOLEUM FLOORS	NOT DECONTAMINATED	117.
WOOD FLOORS	u	9570.
WOOD FLOORS	NOT DECONTAMINATED	18.
CARPETED FLOORS	V	20178.
CARPETED FLOORS	v	234.
CARPETED FLOORS	VF	75.
CARPETED FLOORS	vF	1911.
CARPETED FLOORS	NOT DECONTAMINATED	81.
CONCRETE FLOORS	u	8899.
CONCRETE FLOORS	v	1652.
CONCRETE FLOORS	NOT DECONTAMINATED	102.
INT'R WOOD/PL WALLS	NOT DECONTAMINATED	358.
INT'R CNCRETE WALLS	NOT DECONTAMINATED	77.
ASPHALT STRTS/PRKNG	V	12165.
ASPHALT STRTS/PRKNG	F	4447.
ASPHALT STRTS/PRKNG	NOT DECONTAMINATED	134.
CNCRETE STRTS/PRKNG	V	10420.
CNCRETE STRTS/PRKNG	F	3860.
CNCRETE STRTS/PRKNG	NOT DECONTAMINATED	117.
ROOFS	V	55001.
ROOFS	H	32170.
ROOFS	NOT DECONTAMINATED	164.
LAWNS	R	5554.
LAWNS	L	189120.
LAWNS	NOT DECONTAMINATED	146.
AUTO EXTERIORS	NOT DECONTAMINATED	4.
AUTO INTERIORS	NOT DECONTAMINATED	4.
AUTO TIRES	NOT DECONTAMINATED	4.
AUTO ENG/DRV TRAIN	NOT DECONTAMINATED	4.
OTHR PAVED ASPHALT	V	1680.
OTHR PAVED ASPHALT	F	1092.
OTHR PAVED ASPHALT	NOT DECONTAMINATED	2.
OTHR PAVED CNCRETE	V	6726.
OTHR PAVED CNCRETE	F	4383.
OTHR PAVED CNCRETE	NOT DECONTAMINATED	8.

TABLE 5.11 Decontamination With Water Specified for Agricultural Fields

DETAILED SURFACE RESULTS FOR GRID ELEMENT 1

*** RAIN ***

PROB. OF RAINISNOW BEFORE DECONTAMINATING... 1.0000

SURFACE	AREA	DOSE	ATDF	METH	DF	COST/M**2	TOT. COST	RATE
AGRICCILTURAL FIELDS	231	85.36	8.9	W	1.3	.021.9	5.07	0
VACANT LAND	90	85.36	8.5	A	20.0	.0280	2.93	1770
WOODED LAND	97	85 36	8.5	TNx	9.3	8.8260	861.06	266
EXTERIOR WOOD WALLS	7	8.54	9	----	....	....	.	
EXTER'R BRICK WALLS	23	8.54	7	----	....	....	....	.....
LINOLEUM FLOORS	18	42.68	4.3	V	20.0	.2700	5.12	69
WOOD FLOORS	1	42.68	4.3	V	6.7	.2700	.54	69
CARPETED FLOORS	11	42.68	4.3	vF	4.6	1.5000	17.02	40
CONCRETE FLOORS	16	42.68	4.3	v	4.7	.5400	8.91	69
INT'R WOOD/PL WALLS	53	4.27	4	----	....	....	....	.....
INT'R CNCRETE WALLS	11	4.27	4	----	....	....	....	.....
A PHALT STRTS/PRKNG	22	85.36	8.5	F	10.0	.0911	2.09	17186
CNCRETE STRTSIPRKNG	19	85.36	8.5	F	10.0	,0911	1.82	17186
ROOFS	24	85.36	8.5	WW	26.7	.4600	11.41	81
LAWNS	16	85.36	8.9	R	50.0	6.0438	97.61	40
AUTO EXTERIORS	1	85.36	8.5	TWW	14.3	60.0000	60.00	1
AUTO INTERIORS	1	85.36	8.5	v	9.5	10.0000	10.00	3
AUTO TIRES	1	85.36	8.5	R	1000.0	225.0000	225.00	1
AUTO ENG/DRV TRAIN	1	85.36	8.5	E	10.0	36.9000	36.90	1
OTHR PAUED ASPHALT	0	85.36	8.5	F	10.0	.0995	.02	8593
OTHR PAUED CNCRETE	0	85.36	8.5	F	10.0	.0995	.09	8593

NOTES

# = QUICK-UAC IN EFFECT + = REQUIRED METHOD " = QUICK-VAC + REQUIRED METHOD
I = RESTRICTED OPERATION(S) * = QUICK-VAC + RESTRICTED OPERATION(S)
1111 = UNABLE TO DECONTAMINATE SURFACE ---- = DECONTAMINATION NOT REQUIRED

TABLE 5.11 (cont.)

SUMMARY RESULTS FOR GRID ELEMENT 1

```
**************************************************************
* MULTIPLY $'s, AREAS AND MAN/EQUIP-HOURS EY:      1 000E+03*
**************************************************************
```

PROGAGILITY OF RAIN/SNOW BEFORE DECONTAMINATING	1 0000.	
RADIATION LIMIT FOR ORGAN 1 IS	10.00	
NUMEER OF TIME PERIODS CONSIDERED IS..........	30	
OPTIMAL- TIME TO DECONTAMINATE IS IN YEAH......	8	
ANNUAL DEPRECIATION FACTOR IS.................	1.0	
DISCOUNT FACTOR IS............................	1.0	
DISCOUNT FOR RESIDUAL. CONTAMINATION IS........	.10	
TOTAL. DECONTAMINATION COSTS ARE.............. $	1345.	
TOTAL AREA DECONTAMINATED IS.................	545.0	SQUARE METERS.
AVERAGE DECONTAMINATION COSTS/M**2 ARE....... $	2.47	
AREA REQUIRING NO DECONTAMINATION IS.........	96.8	SQUARE METERS.
AREA THAT COULD NOT BE DECONTAMINATED IS.....	.0	SQUARE METERS.
PEE-ACCIDENT PROPERTY VALUE IS .... $	8840.	
POST-DECONTAMINATION PROPERTY VALUE IS ...... $	7956.	
NET PRESENT VALUE OF PROPERTY IS .... $	970.	
TOTAL REDUCTION IN PROPERTY VALUE IS .... $	7870.	
WHOLE BODY EXT. DOSE TO RAD. WORKERS IS	1.0.452	MAN-REM.
SIZE OF RESIDENT POPULATION	29.	PERSONS.

TOTAL FACTOR INPUT REQUIREMENTS
(MAN/EQUIPMENT HOURS)

DRIVER. HEAVY TRUCK	2.03
OPERATOR, MED. EQUIPMENT	2.65
OPERATOR, FARM EQUIPMENT	.05
BUILDING LABORER	1.76
COMMON LABORER	2.67
CLEANING WORKER	2.78
FOREMAN	.66
PILOT	.02
FLIGHT CREWMAN	.02
AIR GROUND CREWMAN	.04
SPRAY OPERATOR	.28
FRONT END LOADER	.96
5000 GAL SPRAY TRUCK W/PUMP&BOOM	.11
AIRPLANE	.02
TRACTOR W/PLOW	.05
CHIPPING MACHINE	.37
HYDRAULIC EXCAVATOR	.37
VACUUM, HAND	1.94
PAINT SPRAY EQUIPMENT	.28
TOW TRUCK	1.00
GRADER	.30
VEHICLE WASHING EQUIPMENT	.50
DUMP TRUCK	.92

considerably. Housing interiors, for example, would usually give high exposures while highways and wooded areas would tend to offer lower exposures. The exposure factors are defined as being inversely proportional to the target decontamination factors, and with values in the base case equal to 1.0. Thus, an exposure factor of 2.0 means that it would be necessary to remove from a surface just half of the contaminants that would be required with an exposure factor of 1.0. To illustrate this feature, DECON was run with the exposure factors shown in Table 5.12.

Total decontamination costs fall to $229 million when the exposure factors in Table 5.12 are used, compared with $325 million in decontamination costs in the base case. Furthermore, all of the surfaces could be decontaminted with methods currently in the reference database. Under the base case, grid element 11 could not be decontaminated. A comparison of the net present values of the property for grid elements 11 through 18 is presented in Table 5.13. Varying

TABLE 5.12. Selected Exposure Factors

Surface	Exposure Factor	Surface	Exposure Factor
Agricultural Fields	1.0	Streets/Parking, Asphalt	6.0
Orchards	4.0	Streets/Parking, Concrete	6.0
Vacant Land	10.0	Wooded Land	10.0
Exterior Walls, Wood	1.5	Exterior Walls, Brick	1.5
Floors, Linoleum	0.5	Floors, Wood	0.5
Floors, Carpeted	1.5	Floors, Concrete	1.5
Interior Walls, Painted	0.5	Interior Walls, Concrete	1.5
Roofs	1.0	Lawns	1.3
Auto Interiors	0.9	Auto Exteriors	2.0
Auto Engine/Drive Train	1.6	Auto Tires	5.0
Other Paved Surfaces, Asphalt	1.0	Other Paved Surfaces, Concrete	1.0

TABLE 5.13. Net Present Value of Property Varying Exposures Versus Base Case

Grid Element Number	Net Present Values of Property: Varying Exposure Factors	Net Present Values of Property: Base Case
11	129,000	0
12	8,917,000	485,000
13	20,283,000	7,906,000
14	31,872,000	18,361,000
15	46,759,000	31,133,000
16	427,938,000	327,584,000
17	785,442,000	757,476,000
18	1,100,375,000	1,067,913,000

the exposure factors results in substantially fewer property losses. The differences are particularly striking in the grid elements closer to the point of release.

5.2.7 Cleanup Standards vs. Decontamination Costs

In this part of the analysis, DECON is used to demonstrate how one can establish the relationship between cleanup standards and decontamination costs. Up to this point the radiation limit that has been in effect is a 10-rem 70-year dose commitment. We now consider 70-year dose commitments of 1.0, 2.5, 5.0, 7.5, 15.0, 20.0, 25.0 and 40.0 rem. The results are presented in Table 5.14. They show a clear tradeoff between decontamination costs and cleanup standards or, equivalently, health risks. Decontamination costs vary from $103 million in the case of a 40-rem limit up to $2.1 billion for a 1.0 rem limit. The surface area that requires no decontamination varies from 911 million square meters in the 1.0-rem case to 2,376 million square meters in the 40-rem case.

It is also of interest to determine the effect on property values as the cleanup standard varies. We have already noted that decontamination costs are apparently a relatively minor component of the property losses. The major losses are the result of depreciation and loss of property use when decontamination must be deferred. The stricter is the cleanup standard, the more likely it is that decontamination will be deferred. Table 5.15 presents the value of property, as measured immediately following the accident, for the various cleanup standards. As expected, net present property values clearly rise as the radiation limit rises. At a 70-year dose commitment of just 1.0 rem, the net present value of property in the accident area is $21.7 billions; with a 70-year dose commitment of 40 rem, the net present value of property rises to $39.7 billions. This tradeoff between radiation limits and property losses provides the basis for an informed decision on where to set the radiation limit to protect public health while at the same time keeping down property losses.

TABLE 5.14. Cleanup Standards vs. Decontamination Costs

70-Year Dose Commitment (rem)	Total Cost ($ 000's)	Unit Cost ($/$m^2$)	Area Not Decontaminated (m^2) (Unable to)	(Not Required)
1.0	2,139,282	1.29	18,050,000	911,125,000
2.5	1,786,268	1.07	4,009,000	916,200,000
5.0	1,153,299	.79	2,037,000	1,132,700,000
7.5	615,694	.44	696,000	1,456,000,000
10.0	324,954	.64	696,000	2,080,300,000
15.0	209,546	.55	696,000	2,211,700,000
20.0	190,340	.73	696,000	2,328,000,000
25.0	136,613	.64	0	2,376,500,000
40.0	103,021	.48	0	2,376,500,000

TABLE 5.15. Cleanup Standards vs. Net Present Value of Property

70-Year Dose Commitment (rem)	Net Present Value ($ mill's)
1.0	$21,714
2.5	27,446
5.0	28,729
7.5	29,310
10.0	35,640
15.0	38,113
20.0	39,629
25.0	39,692
40.0	39,738

5.2.8 Conclusions

We have used DECON to explore several strategies for restoring a large site following a major reactor accident. In particular, it has been used to determine the cost-effectiveness of various actions, ranging from restricting the use of methods, through varying allowable exposure rates from different surfaces, to setting the radiation standard itself. The results are apparently particularly sensitive to the discount factor used to evaluate the loss of use of property and the depreciation rate. Losses due to residual contamination may also be substantial.

One potential use of DECON that has not been mentioned thus far is to identify specific situations that are causing inordinately large losses, and then to use this information to find mitigating actions. For example, we observed that the inability to effectively decontaminate wooded areas meant that substantial property losses occur under the rule that all of the property within a grid element is decontaminated at the same time, or none of it is. Because these wooded areas caused long delays in restoring the property within some grid elements and therefore caused substantial property losses, two alternatives are suggested. First, we might want to cordon off the wooded area for several years while allowing the surrounding property to be decontaminated and used; or we might want to expend some resources searching for more effective ways to decontaminate wooded areas. This example illustrates just one of many types of "bottlenecks" that can be found using DECON.

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APPENDIX A

A.0 INTRODUCTION

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

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

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

There are two general approaches to estimating the cost of a particular operation. The first is to construct the cost from information about the production function--i.e., the relationship between physical inputs and output(~)--andthe various input prices. The second approach establishes, from

people actually performing the operation, how much it costs them to perform the operation. Both approaches have problems. In the first, one runs the risk of overlooking an important input or otherwise mis-specifying the production function. The second method may yield misleading results if the sources are subject to some special conditions such as a particular constraint, regulation, or subsidy, or if the source enjoys any substantial market power.

Where possible, we tried to establish cost and productivity data by the second method. We contacted sources which provide or hire the operations in which we were interested. Of course, several of the operations apply only to radiological decontamination; they are not, therefore, customarily supplied in the marketplace. In those cases we had to resort to estimating a crude production function, and we calculated average costs using collected costs of inputs. Throughout, when specific labor costs were not available, we usually assumed the hourly cost for labor to be $17.45 per hour. This is the hourly billing cost for common building laborers reported in Means Construction Costs Data 1981. This figure includes benefits, administrative overhead, and profit. Other rates were used when the required level of skill was high. To the extent that this labor cost figure is too high or too low, the cost figures and input shares of cost reported should be adjusted accordingly.

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

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

One related point is that throughout the report, unit costs and production rates were adjusted to account for the reduced productivity resulting from the special conditions of working in a radioactively contaminated environment. In particular, we assumed that one hour of productive work out of every eight-hour shift was lost due to such things as the necessity of working in cumbersome protective clothing and periodic personnel and equipment contamination. The cost of this extra hour, therefore, results in a higher cost per square meter. In situtations involving severe contamination, this extra hour may still be inadequate, necessitating appropriate adjustments to the data.

Some operations involve two or more distinct steps. For example, resurfacing paved roads requires first that the surface be planed and second that a layer of asphalt be applied. It is frequently the case that the constituent procedures of an operation have different hourly production rates.

The rule for combining procedures of different rates is to make the rate of the total operation equal to the rate of the procedure with the highest cost per square meter. Doing this generally requires that more or less than one crew for other procedures be used.

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

A.l ASPHALT ROADS

A.1.1 Mobile Vacuumized Street Sweeping

While other operations have greater decontamination effectiveness, the cost per square meter of vacuuming is so low in comparison that it would likely be used alone or in conjunction with other procedures in essentially all instances in which pavement decontamination activities are undertaken. There are four basic types of mobile street sweepers in use by cities, highway departments, and airports. These are the mechanical rotary-broom type, the recirculating air type, the vacuum type, and the dustless vacuum type. Within the spectrum of costs encompassed by the various pavement decontamination methods, there is relatively little difference among the costs of using these devices, and the reports from the different sources disagreed as to the ranking of the vacuum types by cost. The least effective for the purposes of radiation decontamination is the mechanical rotary-broom type. This machine is intended primarily for picking up large debris such as cans, bottles, hubcaps, and mufflers. Other machines do a better job of removing small particles and are used most commonly in dusty or sandy locales. The best machine for decontamination purposes is the dustless vacuum type - a machine most commonly used at airports for cleaning runways. Because of its high filtration at the vacuum exhaust and containment skirts underneath, this type of equipment creates little or no airborne dust which could recontaminate neighboring areas.

Unlike some decontamination procedures, vacuumized street sweeping is a common operation. Therefore, it is relatively easy to get fairly reliable cost estimates by using information provided by municipal public works departments and other users of vacuumized street sweepers. The estimates obtained ranged from $0.0020 to $0.0057 per square meter.

The estimates of the cost per square meter are directly tied to the average vehicle operating speed. Users reported a wide range of average speeds - from 1.42 miles per hour to 10 miles per hour. Manufacturers claim effective operation for some models at speeds as high as 15 miles per hour. Actual operating rates are determined by such factors as volume of material collected per unit pavement area, the time necessary to dump collected material, the power of the vacuum, the type of material to be picked up, and the desired cleanliness to be attained. These factors suggest that subsequent vacuumings will be less costly than the first. There will be a smaller volume of material to be picked up, and the material which is picked up is less likely to include branches and other objects which can jam the intake ducts. Even if the vehicles operate at the same average speed while vacuuming, fewer trips to the

dump site will be required per hour and thus total productivity will be higher. Despite the cost difference for subsequent vacuumings, data limitations precluded deriving separate estimates for the different surface treatments.

Vacuumized street sweeping requires a mobile vacuum street sweeper and a driver. Other inputs include such things as fuel, filters, brooms, and maintenance. For purposes of radiation decontamination, it may be helpful to use a sweeping compound. Maintenance is apparently a major expense, and equipment reliability is not very high. Some sources reported that this equipment required as much as one hour maintenance for every three hours operation. The information collected indicated that labor comprised anywhere from 18.5 to 60 percent of sweeping costs. A reasonable estimate based on the more reliable of these figures is that labor comprises 50 percent of vacuuming costs. The remaining costs are for equipment (15 percent), maintenance (25 percent), and fuel (10 percent).

Several factors bear on the effectiveness of vacuumized street sweeping as a decontamination technique. Small particles (diameter less than 10 microns) tend to lodge themselves in surface irregularities and thereby become more difficult to remove than larger particles. The size distribution of particles resulting from a reactor accident is likely to have relatively heavy concentrations of particles in the 1 to 10 micron range (U.S. Nuclear Regulatory Commission 1975). Further, the longer the time between initial exposure and vacuuming, the more difficult will be particle removal, as particles will have become more deeply embedded in the surface. Surface irregularities, both of microscopic and macroscopic sizes, will reduce vacuum effectiveness. The available information on the effectiveness of mobile vacuuming is scant, the best being Radiological Reclamation Performance Summary Vol. II (Owen et al. 1967). Removal efficiencies were also reported by other researchers (Horan et al. 1970; Julin et al. 1978; Wallace et al. 1975; The Product Information Network 1982), spanning a range of from 32 to 98 percent. Further, these sources did not provide any detail as to particle size or the velocity of the mobile vacuum.

Most street sweepers in use are the mechanical rotary-broom type, and while several cities that use vacuum-type sweepers were contacted, only a few of these kept adequate records from which cost per square meter could be calculated. Some cities, such as Walla Walla and Spokane in Washington, use vacuum street sweepers and keep good records, but since street flushing and vacuuming operations and records are combined, it was impossible to identify the respective shares of each.

The City of Kennewick, Washington, uses a vacuumized street sweeper. The interdepartmental rental rate which the Street Department is charged for the vehicle by the equipment pool is $2,600 per month. This covers capital, maintenance, depreciation, fuel, and so forth. To convert this monthly charge to a dollars-per-square-meter figure, we need to estimate the number of hours of operation per month and the average hourly rate of sweeping. The main factor affecting the number of hours worked per month is the number of shifts. With two shifts per day, as opposed to one, the monthly equipment cost can be spread out over twice as many hours and twice the sweeping area. At 176 hours

per month for a single shift, the equipment cost is $14.77 per hour. With two shifts per day, the equipment cost is halved, falling to $7.385 per hour.

The labor cost reported was $10.64 per hour plus 35 percent for benefits and administrative overhead, bringing the total labor cost to $14.36 per hour.

There was considerable uncertainty in establishing a production rate for Kennewick street sweeping, since the Street Department keeps no mileage records. They did indicate that there were 140 street miles in the city, meaning a total of 280 potential production curb-miles. However, not all streets are swept. A total of 250 production miles in the city is a reasonable estimate. These can all be swept in a month if there is no heavy loading of debris as occurs with leaves in the fall. Coverage of 250 miles in the 176 working hours of a month works out to 11.36 miles per shift or 1.42 miles per hour. This is a particularly low speed compared with those reported by other sources. It is also much lower than the top operating speed possible of 5 miles per hour. For the purpose of estimating Kennewick's cost per square meter, the rate of 1.42 miles per hour served as a lower bound for operating speed. Another estimate was derived by assuming 30 miles per shift or 3.75 miles per hour based on production rates reported by other sources.

Assuming one hour per shift is lost to special radiation protection measures, the production rate at 1.42 miles per hour is as follows:

$$1.42 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times\ 7/8 \text{ shift hrs/8-hr shift} = 4882.5 \text{ m}^2/\text{shift-hr}$$

With one shift per day, the total cost per hour is:

$$\$14.77/\text{hr for equip.} + \$14.36/\text{hr for labor} = \$29.13/\text{hr}$$

Dividing by the average hourly production rate of 4883 square meters gives a cost per square meter of $0.0060. With two shifts per day the hourly cost would be:

$$\$7.385/\text{hr for equip.} + \$14.36/\text{hr for labor} = \$21.75/\text{hr}$$

Dividing by the hourly production rate yields an average cost of $0.0045 per square meter.

Alternatively, at an operating speed of 3.75 miles per hour, the estimated production for a shift hour is:

$$3.75 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times\ 7/8 \text{ shift-hrs/8-hr shift} = 12{,}890 \text{ m}^2/\text{shift-hr}$$

At this rate, the cost per square meter with one shift per day is:

$$\$29.13/\text{hr} \div 12{,}890 \text{ m}^2/\text{hr} = \$0.0023/\text{m}^2$$

With two shifts per day, the cost per square meter falls to:

$\$21.75 \div 12{,}890\ m^2/hr = \$0.0017/m^2$

The costs for the separate inputs, labor and equipment, are calculated in the same way. Table A.I.I.I summarizes these results.

Based on these data, a cost of $0.0030 per square meter with an average production rate of 10,000 square meters per hour was selected as representative of Kennewick's street sweeping operations. Labor comprises about 64 percent and equipment about 36 percent of total costs.

,TABLE A.1.1.1. Summary of Vacuumized Street Sweeping Data for Kennewick, Washington

	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment
1.42 mph				
1 shift/day	4883	0.0060	0.0029	0.0030
2 shifts/day	4883	0.0045	0.0029	0.0015
3.75 mph				
1 shift/day	12,890	0.0023	0.0011	0.0011
2 shifts/day	12,890	0.0017	0.0011	0.0006
Representative				
2 shifts/day	10,000	0.0030	0.0019	0.0011

The City of Pasco, Washington uses an Elgin Whirlwind V349 street sweeper. The Public Works Department pays an interdepartmental annual rental fee of $50,700 for the sweeper. This covers all equipment-related costs such as capital, depreciation, interest, maintenance, parts, and fuel. The operator's wage is $9.56 per hour, to which should be added an additional 70 percent for benefits and administrative overhead, according to the city engineer. However, weather, equipment breakdowns, and operator time off prevent regular eight-hour per day operation. On the other hand, the equipment is occasionally operated two shifts per day. These factors make it preferable to use total yearly labor costs rather than hourly figures. Table A.1.1.2 provides this information for the last three years. Direct cost refers to total wages, and total cost represents wages plus 70 percent for benefits and administrative overhead. The figures for 1982 were estimated from data for the first nine months of the year.

Despite detailed information about total mileage, actual production miles had to be estimated. Inspection of the sweeping log for 1982 showed total miles per day ranging from about 19 to about 44. Most days showed mileages between 20 and 30. Comparing the record of engine hours on the vacuum motor to total miles driven, it was estimated that each vacuum engine hour corresponded to three production miles. In all cases this estimate resulted in production miles being somewhat less than each day's total miles as should be the case.

TABLE A.1.1.2. Yearly Labor Cost for Vacuumized Street Sweeping in Pasco, Washington

Year	Costs (1982 $) Direct Cost (Wages)	Benefits and Administrative Overhead	Total Labor Costs
1980	12,292	8,604	$20,896
1981	16,564	11,595	$28,159
1982	19,437	13,609	$33,046

From February 17, 1982, to November 24, 1982, the vacuum engine logged 1415 hours. At 3 miles per hour, this equals 4,245 production miles. Over the same period there were 219 operating shifts. This yields an average 19.38 production miles per shift. For the remaining parts of 1982 we estimated 50 shifts, bringing the total shifts to 269. Multiplying by the miles per shift gives 5214 estimated production miles for 1982.

Multiplying total hourly cost for labor ($16.252) by the number of shifts (269) and by 8 hours per shift produces an estimated total labor cost of $34,974. This is somewhat more than the $33,046 listed earlier. The difference is apparently due to the operator's working at sweeping for less than 8 hours on some shifts. The total number of sweeper operator hours for the year was about 2033. The average hours per shift was about 7.55.

The following converts total vacuum miles to area, assuming an 8-foot width:

$$4245 \text{ prod. miles} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$= 16{,}675{,}718 \text{ m}^2/\text{yr}$$

Allowing for one hour out of eight for radiation decontamination gives:

$$16{,}675{,}718 \times 7/8 = 14{,}591{,}253 \text{ m}^2/\text{yr}$$

The cost per square meter is:

$$\$83{,}746 / 14{,}591{,}253 \text{ m}^2 = \$0.0057/\text{m}^2$$

Hourly production is:

$$14{,}591{,}253 \text{ m}^2 / 2033 \text{ hrs} = 7177 \text{ m}^2/\text{hr}$$

The share of costs accounted for by labor is:

$$\frac{\$33{,}046}{\$83{,}746} = 39.5\%$$

and the share for capital (including fuel, maintenance, etc.) is 60.5 percent. In other words, the cost per square meter for labor is $0.0023 and the cost per square meter for capital is $0.0034.

The Department of Public Works in San Francisco supplied detailed cost information on their street sweeping operations. Their costs by major input, in terms of production miles, are:

TABLE A.1.1.3. Street Sweeping Costs by Input for San Francisco, California

Input	Cost (1982 $/lane mi)	Percent of Total
Fuel	1.28	9.3
Maintenance and repair	2.88	21.0
Capital	1.78	13.0
Labor	7.76(a)	56.8
Total	13.70	100.0(b)

(a) Labor cost at 7.56 per mile plus $5.00 per shift. Shift differential converted to cost per mile based on 25 miles per shift.
(b) Parts do not add to 100 due to rounding.

Of the four input categories, only labor and equipment need to be adjusted for the one hour per shift for radiation control. This is accomplished by multiplying by 8/7 to give $8.87 per mile. With an eight-foot wide sweeper swath, one mile of sweeping will cover 3928 square meters. Dividing the total cost per lane mile, $15.06, by 3928 yields a cost of $0.0038 per square meter. These calculations are summarized in Table A.1.1.4.

San Francisco uses 15 Tymco recirculating air street sweepers. The operation performance standard is 25 production miles per eight-hour shift, and

TABLE A.1.1.4. Adjusted Street Sweeping Costs by Input for San Francisco, California

Input	(Cost (1982 $) $/lane mi	$/m^2	Percent of Total
Fuel	1.28	0.0003	8.5
Maintenance and repair	2.88	0.0007	19.1
Capital	2.03	0.0005	13.5
Labor	8.87	0.0023	58.9
Total	15.06	0.0038	100.0

this standard is reportedly very close to actual production mileage. The hourly production rate, adjusted for one hour per shift for radiation control, is:

$$25 \text{ mi/shift} \div 8 \text{ hrs/shift} \times 5280 \text{ ft/mi} \times 8 \text{ ft width} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times\ 7/8 \text{ hrs/shift} = 10{,}742 \text{ m}^2/\text{hr}$$

The Maintenance and Operations division of the Washington State Department of Transportation reported their street sweeping costs as follows:

TABLE A.1.1.5. Street Sweeping Costs by Input for Washington State Department of Transportation

Input	Cost (1982 $/lane mi)
Labor	9.55
Equipment	11.82
Materials	0.15
Total	21.52

Washington uses mechanical rotary broom type sweepers. Nonetheless, their cost and productivity information is reported here since it seems to be not greatly different from other road sweeping information.

As with the San Francisco data, the labor figure must be adjusted for one hour per shift for decontamination by multiplying by 8/7. This gives the adjusted costs shown in Table A.1.1.6.

The Washington Department of Transportation defines a lane mile as having a width of 12 feet. This gives an area of 5892.48 square meters per lane

TABLE A.1.1.6. Adjusted Street Sweeping Costs by Input for Washington State Department of Transportation

Input	Cost (1982 $)		Percent of Total
	$/lane mi	$/m²	
Labor	10.91	0.0019	47.7
Equipment	11.82	0.0020	51.7
Materials	0.15	0.0000	0.7
Total	22.88	0.0039	100.0[a]

[a] Parts do not add to 100 due to rounding.

mile. Dividing this figure into the cost per lane mile gives a cost of $0.0039 per square meter. Sweepers, however, have an effective sweeping width of 8 feet. It would therefore seem necessary to adjust upward the cost to reflect using an 8-foot sweeper on a 12-foot wide lane. The adjusted area of a lane mile is computed as follows:

$$8 \text{ ft wide} \times 5280 \text{ ft/mi long} \times 0.093 \text{ m}^2/\text{ft}^2 = 3928.32 \text{ m}^2/\text{lane mi.}$$

Recalculating the cost per square meter yields $0.0058.

The average production is 1.43 lane miles per hour. After allowing for one hour per shift for radiation control, we obtain an average hourly rate of production of:

$$1.43 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 12 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times 7/8 \text{ production hrs/shift hr} = 7373 \text{ m}^2/\text{hr}$$

The Maintenance Section of Cal-Trans, State of California, operates a mixed vacuum and mechanical sweeper fleet. The model of vacuum sweeper used is an FMC Model 12 Sanavac. For the 1981-82 fiscal year they recorded a total 114,432 "broom-down" (production) miles and a total cost of $4,638,773. The cost breakdown is shown in Table A.1.1.7.

These figures are considerably different from those reported by other sources. A simple gross calculation of the cost per square meter based on total production miles and total cost yields a cost per square meter of

TABLE A.1.1.7. Street Sweeping Cost Breakdown from Cal-Trans, State of California

Input	Percent
Salaries	43
Equipment	55
Material	1
Other	1
Total	100

$0.0103. This figure is much higher than those calculated from data supplied by other sources. Further inquiry revealed that about half of the Cal-Trans sweeping miles require an escort truck as a safety feature to warn passing traffic. Also, the Cal-Trans operation must be different in other respects, as evidenced by the existence of five-person sweeping crews. Their standard crew consists of one supervisor, one lead worker, and three workers. Salaries are in the range of $10 to $12 per hour.

Apparently, the Cal-Trans sweeping operation entails considerably more than just mobile street sweeping. Cleanup of litter on shoulders, medians, and culverts, as well as minor road maintenance, may be involved. The problem

is to adjust the Cal-Trans figures to reflect the cost of sweeping alone. A few simple, crude steps were taken to get a rough estimate for sweeping costs. The first was to divide the labor costs by five, since we are interested in a one-man, one-sweeper operation. The second step was to reduce the equipment cost to account for the unneeded escort vehicle. If the cost of an escort truck is half the cost of the sweeper, and the escort truck is used on half the sweeper miles, then the escort truck generates roughly 25 percent of the total equipment costs. Multiplying equipment costs by 0.75 yields the adjusted figure. The adjusted figures are shown in Table A.1.1.8.

TABLE A.1.1.8. Adjusted Street Sweeping Figures from Cal-Trans

Input	Cost (1982 $)
Salaries	398,934
Equipment	1,913,494
Materials	46,388
Other	46,388
Total	2,405,204

This total cost figure yields a cost per square meter of $0.0054. Making the further adjustment to labor costs to account for radiation control by multiplying by 8/7 yields the costs shown in Table A.1.1.9.

TABLE A.1.1.9. Adjusted Street Sweeping Costs by Input for Cal-Trans, State of California

Input	Cost (1982 $) $/yr	Cost (1982 $) $/m^2	Percent of Total
Labor	455,925	0.0010	18.5
Equipment	1,913,494	0.0043	77.7
Materials	46,388	0.0001	1.9
Other	46,388	0.0001	1.9
Total	2,462,195	0.0055	100.0

The costs per square meter in Table A.1.1.9 were calculated by dividing the cost per year by the area covered per year, which is:

$$114{,}432 \text{ mi/yr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$= 449{,}525{,}514 \text{ m}^2/\text{yr}$$

These calculations produce a total cost per square meter of $0.0055.

Despite these adjustments, these figures are still considerably higher than those reported by other sources. In particular, the figure of 77.7

percent of total cost for equipment is quite high compared with other sweeping operations in which figures of 40-60 percent are more common. Another question results from Cal-Trans' estimate of an average sweeping speed of 7.5 miles per hour. In general, high sweeping speeds will lead to low costs per unit surface area, and this speed is the highest speed reported from the sources contacted. Using this speed and adjusting for one hour per shift in which no vacuuming is done, we get:

$$7.5 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8$$
$$= 25{,}780 \text{ m}^2/\text{hr}$$

McGraw-Hill publishes a document called PIN or Product Information Network which is compiled by the International City Management Association–and the McGraw-Hill Information Systems Conipany. In September, 1982 the volume concerning street sweepers was revised. This document contains a general discussion of street sweeping equipment as well as providing information on prices and performance of various types of equipment.

On page 17, PIN reports an annual cost of $350 per curb mile per year for vacuumized sweeping with one pass every five days. If "one pass every five days" is interpreted to mean once a week or 50 times per year, then the cost per curb mile per pass is $350/50 = $7.00. The cost per square meter, based on an 8-foot width, is $0.0018. Multiplying by 8/7 to adjust for time for radiation control brings the cost to $0.0020 per square meter.

PIN did not provide information on the average operating speed corresponding to the cost estimate of $350 per curb mile per year. Elsewhere in the text (p. 11), a speed of 2 miles per hour was described as producing "very good" results and a speed of 4 to 5 miles per hour as resulting in a good compromise between productivity and cost. If we assume an average operating speed of 2.5 miles per hour, including time for dumping collected debris, then the average decontamination coverage per shift-hour would be:

$$2.5 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 8 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ shift-hrs/hr}$$
$$= 8593 \text{ m}^2/\text{hr}$$

While PIN discussed some aspects of sweeping costs in detail, nothing was provided which would permit calculation of the respective cost shares of the various inputs into street sweeping operations.

While the Radiological Reclamation Performance Summary, Vol. II (Owen et al. 1967) did not report any cost figures, sweeping coverage rates were listed. Actual rates were adjusted downward by the authors by 15 percent to compensate for the ideal test conditions. Further, this source listed the net rates incorporating the effects of necessary overlap of successive sweeping swaths. This has the effect of reducing the effective sweeping width to about 3.5 to 4.0 feet. The actual sweeping width of the machines used was not reported. Separate results for a variety of test results for different

conditions were listed. These alternate conditions included sweeper type, pavement texture, initial mass loading of contaminant, particle size, and sweeper speed. Results from test conditions that most closely replicate the conditions likely to occur in the event of a reactor accident are reproduced here in Table A.1.1.10. Coverage rates in terms of square meters per hour range from 3,962 to 18,972. This wide range encompassed all the rates reported by other sources except that for Cal-Trans. It is clear that the operating rate is not fixed by the vehicle's capabilities so much as by other factors. A major criterion might be the associated removal efficiency, but here, too, a representative rate is not immediately apparent. The conventional mechanical street sweeper achieved a first-pass removal efficiency of 62 percent for 74-177 micron-sized particles on rough pavement at the very high coverage rate of 18,972 square meters per hour. This was only nominally better than the removal efficiency reported at 5,915 square meters per hour for the same conditions. We calculated a representative rate for these tests by averaging the coverage rates for all tests for which the first-pass removal efficiency was greater than 50 percent. This yields a figure of 9732 square meters per hour.

However, the nature of the test procedures requires some further adjustments. In particular, no time was alotted for the effects on productivity for working in a radioactive environment. Also, the production rates given by this source do not include any time for dumping collected materials. Assuming that one hour per shift would account for reduced productivity resulting from the hazardous environment and that half an hour per shift would be necessary for dumping, we get an adjusted coverage rate of:

$$\frac{9732 \text{ m}^2/\text{hr} \times 6.5 \text{ hrs}}{8 \text{ hrs}} = 7907 \text{ m}^2/\text{hr}$$

Table A.1.1.11 summarizes the data on vacuumized sweeping costs. Also shown are representative rate and cost data.

The average hourly production rates from the various sources are reasonably close, except for the Cal-Trans figure. In averaging the rates to arrive at a representative hourly figure, the Cal-Trans value was ignored.

The cost data cover a broader span. While the PIN figure is quite low, it supposedly represents an average taken from several municipalities. For this reason it was included in computing the average, which is the basis for the representative cost figure.

All sources that disaggregated their costs by input groups listed labor as a separate category. However, there was considerable variation in the way that non-labor costs were categorized, making input costs hard to synthesize. The approach used here was to add all the non-labor costs together into a composite input called equipment. Representative input costs are calculated as simple averages, excluding the Cal-Trans figures. The input cost proportions reported by the San Francisco Department of Public Works could be used as a rough guide for further input cost disaggregation, if necessary.

TABLE A.1.1.10. Selected Street Sweeping Data

Sweeper Type	Pavement Texture	Particle Size (μ)	Gear	Speed (mph)	Rate		Effective Width (ft)	Pass and Marginal Removal Efficiency (%)				
					(ft^2/min)	(m^2/hr)		1	2	3	4	5
Mechanical	Rough	74-177	1	2.5	1,060	5,915	4.8	64	67	67	45	18
			2	6.0	2,130	11,885	4.0	62	64	41	10	--
			3	9.5	3,400	18,972	4.1	62	63	60	44	22
Vacuumized	Rough	44-74	1	2.5	710	3,962	3.2	64	17	--	--	--
			2	5.0	1,550	8,649	3.5	38	32	19	12	--
			3	8.0	2,430	13,559	3.5	30	26	19	14	6
Vacuumized	Smooth	44-74	2	4.5	1,420	7,924	3.6	82	64	21	--	--

Note: Initial mass loading of contaminant was five grams per square foot. Tests were performed under temperate weather conditions.

Source: Radiological Reclamation Performance Summary, Vol. II

TABLE A.1.1.11. Summary of Vacuumized Street Sweeping Cost Data

Source	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment[(a)]
Kennewick Street Dept.	10,000	0.0030	0.0019	0.0011
Pasco Pub. Works	7,177	0.0057	0.0023	0.0034
San Francisco Pub. Works	10,742	0.0038	0.0023	0.0015
Washington Dept. of Trans.	7,373	0.0056	0.0019	0.0020
California Cal-Trans	29,462	0.0055	0.0010	0.0045
PIN	8,593	0.0020	--	--
Owen et al.	7,907	--	--	--
Representative	8,632	0.0043	0.0021	0.0022

(a) Equipment includes all non-labor costs.

A.1.2 Low-Pressure Water Wash

Using mobile street flushers to apply a low-pressure water wash to paved surfaces is the least costly decontamination operation per square meter. Further, the decontamination efficiency of this operation is fairly high--95 percent on the first pass for pavement on which there has been no rain. However, this procedure results in a byproduct of a certain amount of contaminated water, which leads to the important question of what, if anything, to do with this water. In this section the flushing operation and the calculation of the costs of flushing per unit area will be discussed.

The City of Los Angeles calculates the average cost of mobile street flushing at $9.08 per mile for all inputs, including labor, equipment, maintenance, fuel, and so forth, including an average ten percent down time for the flushers. This cost varies with factors such as terrain; they estimate the cost per mile over flat areas at $5.68 per mile and $23.00 per mile in hilly areas. Despite this cost detail by terrain, they have no data on the costs of the different inputs.

According to this same source, the average net speed is five miles per hour. Therefore, in an average eight-hour shift the flusher will cover 40 miles. If we adjust this rate by a factor of 7/8 to account for radiation control measures, the mileage per shift is 35.

The flushers average 10 percent down time. That means for an average 8-hour shift, the flusher is available for 7.2 hours. During operation, the average speed is 5 miles per hour. Therefore, in an average 8-hour shift the flusher will cover 7.2 hours x 5 mi/hr = 36 miles. If we adjust this rate by a factor of 7/8 to account for one hour per shift for special radiation control operations and reduced productivity, the mileage per shift is 31.5.

Flushers may be configured to flush one or both sides of the street at a time. The normal practice seems to be to flush one side at a time. That is the practice adopted by Los Angeles, and it on this basis that most flushing costs were calculated in this report. While street widths vary, a reasonable average width according to this source is 40 feet. That makes the width of a flush 20 feet. The coverage per shift hour is, then:

35 mi/shift x 5280 ft/mi x 20 ft wide x 0.093 m^2/ft^2

÷ 8 hrs/shift = 42,966 m^2/shift-hr

Assuming that the cost per shift will not fall in direct proportion to the drop in output due to seven rather than eight hours of production, the cost per square meter is calculated on the basis of an unchanged total cost per shift, even with only seven production hours out of eight. Therefore, the cost per shift hour is:

$$\frac{\$9.08/\text{mi} \times 40\ \text{mi/shift}}{8\ \text{hrs/shift}} = \$45.40\ \text{per hour}$$

The cost per square meter is, then

$\$45.40/\text{hr} \div 42{,}966\ m^2/\text{hr} = \$.0011/m^2$

The Public Works Department of the City of San Francisco provided its costs per mile for flushing, broken down by input as shown in Table A.1.2.1. The production rate is 40 lane-miles per 8-hour shift for an average 5 miles per hour. This figure includes time for refilling and breakdowns. Reducing the productivity rate by an hour per shift to account for necessary radiation control brings the average hourly speed down to 5 x 7/8 = 4.375. The average hourly production, then, is:

4.375 mi/hr x 5280 ft/mi x 20 ft wide x 0.093 m^2/ft^2 = 42,966 m^2/hr

As with the Los Angeles flushing data, we again assume that per shift costs would not be reduced by the hour per shift spent on radiation control measures. The cost per square meter is therefore calculated in the following manner:

$$\frac{\$8.07/\text{mi} \times 40\ \text{mi/shift}}{42{,}966\ m^2/\text{shift hr} \times 8} = \frac{\$322.8/\text{shift}}{343{,}728\ m^2/\text{shift}} = \$0.0009/m^2$$

TABLE A.1.2.1. Flushing Costs by Input From the Public Works Department, City of San Francisco

Input	Cost (1982 $/mi)
Fuel	0.80
Maintenance and equipment	1.20
Equipment	1.00
Labor	5.07
Total	8.07

Input costs per square meter are calculated on the basis of the cost shares for the different inputs as reported by the City of San Francisco. Therefore, the estimated costs per square meter are as shown in Table A.1.2.2.

The City of Seattle Public Works Department reported that over fiscal year 1981-82 the cost of street flushing operations was $139,601. There were a

TABLE A.1.2.2. Estimated Flushing Costs from the City of San Francisco

Input	Percent of Total	Cost (1982 $/m^2)
Fuel	10	0.0001
Maintenance and repair	15	0.0001
Equipment	12	0.0001
Labor	65	0.0006
TOTAL	100	0.0009

total of 10,169 production miles, so the cost per mile averaged $13.72. The flusher is leased interdepartmentally from the city's Department of Administrative Services at $20.38 per hour. This covers fuel, maintenance, depreciation, interest, capital, and so forth. The cost of the driver, including benefits and administrative overhead, is $22.50 per hour. The cost of flusher and driver together come to $340 per shift. Output per shift is 25 miles.

Adjusting output by 7/8, we get a per-shift output of 21.875 miles. With a flush width of 20 feet, this amounts to 214,830 square meters per shift or 26,854 square meters per hour. Dividing the cost per shift by the output per shift yields a cost per square meter of $0.0016. The Seattle figures indicate that equipment, maintenance and repairs, depreciation, and so forth comprise 47 percent of sweeping costs while labor comprises the remaining 53 percent. Converting these percentages to cost per square meter gives $0.0008 for equipment (non-labor inputs) and $0.0008 for labor.

The City of Portland Bureau of Maintenance operates three mobile flushers, each a part of a street cleaning crew. Because the operations of flushing and sweeping are combined and because other operations such as traffic control are also included, the separate costs of street flushing are difficult to infer.

Total curb mileage for all three crews for the 1981-82 fiscal year was 28,097 miles. Dividing by 3, since there are 3 crews, gives 9,366 miles per flusher per year. The cost per flusher per year was given as $140,000, but it was impossible to confirm this figure in subsequent conversations. Further, it is not clear if this was the cost for the flusher alone, or for flusher, labor, and so forth. The assumption made here is that $140,000 represents all costs for flusher, labor, etc. to cover 9366 miles in one year.

The following calculates the cost per square meter and adjusts for seven hours production in an eight-hour shift:

$$\frac{\$140{,}000 \text{ per year}}{9366 \text{ mi/yr} \times 5280 \text{ ft/mi} \times 20 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft} \times 7/8} = \$0.0017/\text{m}^2$$

The average hourly rate of a flusher is easier to calculate. The total 28,097 curb miles for one year took a total of 819 shifts. This works out to an average of 34.3 miles per shift. The adjusted average hourly rate is:

$$34.3 \text{ mi/shift} \times 5280 \text{ ft/mi} \times 20 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$\times\ 7/8 \text{ productive hrs/shift} \times 1/8 = 36{,}843 \text{ m}^2/\text{hr}$$

The Portland data also included some useful figures regarding the costs for the different inputs. They have three street maintenance crews consisting of five people in each. Each crew consists of the items shown in Table A.1.2.3.

TABLE A.1.2.3. Typical Street Maintenance Crew, City of Portland

Labor	Capital
2 sweeper drivers	2 mobile sweepers
1 flusher driver	1 mobile flusher
1 utility worker	1 pickup truck
1 laborer	-----

They provided costs by input for the combined operations of all three crews. They also provided the cost by input for some of the flushing operations alone. More specifically, these are the costs of flushing the core (business) area and arterials. Excluded are the costs of flushing residential areas.

TABLE A.1.2.4. Portland Street Flushing Cost Data

Input	Cost of All Operations 1982 Dollars	Percent	Cost of Flushing Limited Area 1982 Dollars	Percent
Labor	457,000	55	108,000	55
Materials	13,000	2	4,000	2
Fleet	364,000	44	82,000	42
Unspecified	2,000	0	1,000	1
Total	836,000	100[a]	195,000	100

[a] Parts do not add to total due to rounding.

While the mileage corresponding to the limited flushing figures was not available, the data were useful in showing that the cost shares of the various inputs are fairly constant, so that even with incomplete information on flushing we can be reasonably confident that the proportions calculated for the limited area are likely to be very close to the proportions of total sweeping costs. Applying these proportions to the estimated cost per square meter, we can estimate the input costs per square meter, as shown in Table A.1.2.5.

The September, 1982 version of PIN's (Product Information Network) report on street sweepers includes information on the cost of mobile street flushing. They report (p. 17) that the annual cost of flushing is $150 per

TABLE A.1.2.5. Street Flushing Input Costs, City of Portland

Input	Percent of Total	Cost ($/m^2)
Labor	55	0.0009
Materials	2	0.0000
Fleet	42	0.0007
Unspecified	1	0.0000
TOTAL	100	0.0017

curb mile per year with one flush every five days. Interpreting this to mean one pass per week or 50 passes per year, the cost per curb mile per pass is $3.00. Note that this figure is substantially less than any other reported.

The cost per square meter (adjusted for production in only seven of eight shift hours) was calculated as follows:

$$\frac{\$3/mi}{(5280\ ft/mi \times 20\ ft\ wide \times 0.093\ m^2/ft^2)} \times \frac{8}{7}\ adj = \$0.0003$$

The document indicated that the flusher operated at the same speed as a street sweeper (about 8593 square meters per hour). This is problematical for two reasons. The first is that the other sources providing flushing data indicated that flushers normally operate at about twice the forward speed of street sweepers. The second reason to suspect a faster forward speed is that procedures such as these, which are capital- and labor-intensive rather than materials-intensive, will tend to have lower costs at faster rates. Since the cost given here is quite low, one would expect a corresponding faster than average speed. The result of these considerations is to conclude that the information in PIN does not provide a sound basis for estimating production rates. The information in PIN also provides no basis for calculating the shares of total costs by input.

The Maintenance and Operations Division of the State of Washington Department of Transportation estimates its cost of street flushing at $11.71 per lane mile. Its performance standard for flushing is 1.667 lane miles per hour, a much lower rate than reported by other sources. The area flushed in one hour, adjusted for time for radiation control, is:

$$1.667\ mi/hr \times 5280\ ft/mi \times 20\ ft\ wide \times 0.093\ m^2/ft^2 \times 7/8$$
$$= 14{,}325\ m^2/hr$$

At 1.667 miles per hour, Washington's cost per hour is:

$$1.667\ mi/hr \times \$11.71/mi = \$19.52/hr$$

Dividing the cost per hour by the average hourly production yields the cost per square meter:

$$\frac{\$19.52}{14{,}325} = \$0.0014/m^2$$

According to this source, the cost of street flushing can be broken down as shown in Table A.1.2.6. Input costs per square meter are estimated by applying the same input cost shares already reported to the (adjusted) cost per square meter.

The Radiological Reclamation Performance Summary, Vol. II (Owen et al. 1967) reports detailed performance data reqarding mobile street flushers but provides no information about costs. The performance figures in Owen et al. are somewhat at variance with those supplied by other sources. The major difference is that the tests and subsequent calculations for coverage rate and

TABLE A.1.2.6. Washington State Department of Transportation Estimates of Street Flushing Costs by Input

Input	Reported Cost (1982 $/mi)	Reported Percent[a]	Adjusted Cost (1982 $/m^2)
Labor	6.06	52	0.0007
Equipment	5.11	44	0.0006
Materials	0.54	5	0.0001
TOTAL	11.71	100	0.0014

(a) Parts do not add to total due to rounding.

removal efficiencies reported by Owen et al. were based on an average effective flushing width of about 5.2 feet rather than the 20 feet reported by other sources. Vehicle speed was 6 miles per hour. As mentioned earlier, the usual practice for flushing streets is for the mobile flusher to direct a spray of water from the center of the street toward the curb. In this manner, either one or both halves of an average 40-foot wide urban street can be flushed in one pass. The apparent assumption in the Radiological Reclamation Performance Summary was that greater water pressure and, hence, greater scouring action of a direct water spray was necessary to produce sufficient removal. Other available sources concerned with mobile street flushing as a method of radiation decontamination provide no details about the flushing procedure.

This low flushing width was partially offset by an average effective operating speed of 6 miles per hour, which is faster than that reported by most other sources. Even so, the reported coverage rate of 15,345 square meters per hour in Owen et al. is still comparatively low. Adjusting for an hour per shift due to radiation control measures, we get:

$$15{,}345 \text{ m}^2/\text{hr} \times 7/8 = 13{,}427 \text{ m}^2/\text{hr}$$

The previously reported flushing data from other sources resulted in low unit costs in large part because of the high rate of coverage. If a 20-foot flushing width per pass is unrealistic, then the previously reported costs could be converted to a 5-foot width basis by multiplying all cost figures by 4 (20 ft ÷ 5 ft = 4). This adjustment seems more appropriate than the alternative one of increasing unit costs by the ratio of the estimated coverage rates:

$$\frac{\text{est. coverage rate for source A}}{\text{est. coverage rate for Owen et al.}} \times \text{est. unit cost for source A}$$

$$= \text{adjusted unit cost for source A}$$

This adjustment, which converts all costs to an hourly coverage rate of 13,427 square meters, suppresses the collected information on vehicle speed. In

addition to assuming an effective flushing width of about five feet, it also assumes an average speed of 6 miles per hour.

An important reason for not adjusting all costs and rates to a narrower width basis is that a narrow width, direct water spray method is analyzed in the next section. Those cost and rate estimates can be used if 20-foot wide flushing proves unsatisfactory.

A final detail reported by Owen et al. is that the flusher discharged water at the rate of 370 gallons per minute, for a coverage of 0.13 gallon per square foot. Also, nearly half of the operating time was spent in refilling the flusher.

Table A.1.2.7 summarizes the foregoing mobile street flushing data. While most of the" figures are fairly consistent, the PIN data show an exceptionally low rate and low unit cost, and the rate reported by Owen et al. is slightly below that for the Washington Department of Transportation. All rates were

TABLE A.1.2.7. Summary of Mobile Street Flushing Data

Source	Rate (m^2/hr)	Cost (1982 $\$/m^2$)		
		Total	Labor	Non-Labor
Los Angeles Pub. Works	42,996	0.0011	---	---
San Francisco Pub. Works	42,996	0.0009	0.0006	0.0003
Seattle Pub. Works	26,854	0.0016	0.0008	0.0008
Portland Bur. of Maint.	36,843	0.0017	0.0009	0.0008
PIN	8,593	0.0003	---	---
Washington Dept. of Trans.	14,325	0.0014	0.0007	0.0007
Owen et al.	13,427	---	---	---
Representative	26,576	0.0013	0.0007	0.0006

averaged to produce the representative rate. The PIN unit cost was omitted in computing this cost.

Of the sources that provided data for allocating input costs, all designated labor as one of the categories. Beyond that, however, the categories varied- Potential inconsistencies were resolved by lumping all non-labor

costs together. The representative input unit costs were calculated in two different ways, but which produced the same result. In the first method, the four input costs were averaged and then proportionally adjusted to the representative total cost. The other method was to convert each source's input cost to a percentage of total unit cost and then to average these percentages. Then the average input cost shares were applied to the $0.0013 per square meter unit cost to give the input costs.

A.1.3 High Pressure Water

Using a high pressure water wash of 80 to 120 pounds per square inch has the advantage of scouring the pavement. This will result in greater removal of small particles and particles which have penetrated into surface irregularities. There are three basic methods for carrying out this procedure. The first method requires a high pressure fire hydrant system. Crews of two or three workers equipped with a small amount of equipment, primarily fire hoses and nozzles, move from hydrant to hydrant hosing down the pavement by section.

The second method would be used principally in cases where there were no hydrants or where the hydrant system provided inadequate pressure. In this method, water from a hydrant or from a water tanker truck would be supplied to a pump truck which would boost the pressure and supply it to one or two hose lines.

The third method is to use a tank truck fitted with a pump and a set of spray nozzles mounted on a boom across the front of the truck. This equipment would have the capability of applying the water over the width of a lane and would be able to move forward while spraying.

Each of the three methods is discussed in detail below, and cost estimates are given for each. These estimates are weaker than some others in this study due to the fact that high pressure washing of pavement is not an activity which is commonly performed. Therefore, cost estimates were constructed from information on the factor inputs and their likely costs; the estimates are generally not based on experience.

The method using the least amount of specialized equipment requires equipping two- or three-man crews with about 500 feet of firehose (in 50-foot sections with coupling fixtures), a nozzle, a hydrant wrench, and a limited amount of miscellaneous personal equipment, such as rubber boots and other waterproof and protective clothing. The hoses would be connected to a hydrant and used to spray the pavement. Two people may be required to hold the hose if higher pressures are used. After spraying the pavement, workers would drag the hoses to the next hydrant and repeat this operation.

It is interesting that some data from a similar operation was recorded from actual experience in the cleanup of volcanic ash following the eruption of Mount St. Helens in 1980. That event created a situation not entirely unlike the one which would result from a nuclear reactor accident. While the ash did not create a radiation hazard, the sheer volume of material made a large-scale cleanup program necessary. Of course, removing a large volume of ash is not the same as removing an essentially invisible coating of radioactive fallout.

However, in some cases the costs and methods of the two may be similar. For example, in the absense of better data, the cost and rate for hosing a thick coating of volcanic ash from paved surfaces might be a good proxy for the cost of hosing paved surfaces to remove a thin but tenacious coating of radioactive particles. Both operations require a degree of thoroughness - one in order to remove a high volume of material and the other to remove particles with great adhesion to the surface.

The Administrative Services Manager of Spokane Community College directed the cleanup of that campus. Of the total 200 acres, 110 acres were paved. He reported that, on average, one man could hose down a length of street a block long in one hour. Including sidewalks, he estimates the area covered in an hour at 15,000 square feet. This estimate was the result of actually timing the operation. In addition, 15 minutes were required to move the hose from one hydrant to the next. This brings the effective rate down to 15,000 square feet every 75 minutes. If one hour per shift is devoted to equipment and personnel decontamination activities, the coverage rate is:

$$15{,}000 \text{ ft}^2 \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ prod. hrs/shift} \div 1.25 \text{ hrs}$$
$$= 977 \text{ m}^2/\text{hr}$$

The average straight-time salary at the time of the eruption was $6.00 per hour. Here we use a burdened labor cost figure of $17.45 per hour. In addition to these costs were the costs for equipment. This same source reported that the hose and most fittings had to be replaced after two weeks of round-the-clock use. (Sources in the Seattle Fire Department indicated that they would expect a shorter life than two weeks if the hoses were regularly dragged across pavement.)

Apparently, various hose setups were tried. The one for which they reported the greatest success was a Y-setup with one 2-1/2-inch connection to a hydrant. The 2-1/2-inch hose, in (usually) six 50-foot sections led to a Y-valve to which two lines of 1-1/2-inch hose were connected. The 1-1/2-inch lines were usually comprised of 50-foot sections. Each 1-1/2-inch line was separately manned. There was a nozzle at the end of each 1-1/2-inch line, of course. This source reported the cost of 1-1/2-inch hose at $1.30 per foot and the cost of 2-1/2-inch hose at $1.70 per foot. These costs include couplings and their attachment to the hose. Without including the Y-valve or the nozzles, the cost for this apparatus comes to $900.

The general magnitude of these prices was confirmed by a company which specializes in fire hose equipment, Sherman Supply and Salvage Co. in Seattle. Its price information is presented in Table A.1.3.1. A standard length of hose is 50 feet and prices include couplings. Double jacket hose will handle higher pressures than single jacket and will wear longer when the hose is being dragged.

Periodic replacement of the worn-out hose would cost somewhat less than the amounts given because the fittings could be reused. On the other hand,

TABLE A.1.3.1. Calculation of Hosing Equipment Costs

Item	Quantity	1982 $ Price	1982 $ Cost
2-1/2 inch hose, 50 foot length, double jacket	6	$75	$450
1-1/2 inch hose, 50 foot length, double jacket	6	$55	$330
Y fitting 2-1/2" - 2x1-1/2" with valves	1	$86.59	$ 86.59
Industrial fog nozzle, with valve	2	$22.50	$ 45.00
Total			$911.59

Source: Sherman Supply & Salvage Co., Seattle, Washington.

the Seattle Fire Department was skeptical whether a fire hose would last even as short a period as two weeks with constant dragging over pavement. For this work we used a figure corresponding to $1000 for every 2 weeks of continual use. The additional cost was to account for incidental equipment expenditures such as personnel water protection clothing. The equipment cost per hour, then, is:

$$\frac{\$1000}{2 \text{ wks} \times 7 \text{ days} \times 24 \text{ hrs}} = \$2.98/\text{shift-hour}$$

Adding this to the cost of labor brings the total cost per hour to $20.43. Dividing this by the average hourly production gives a cost per square meter of $0.021.

Owen et al. reported detailed performance information for firehosing, but no cost data. The most important of these results for the purposes at hand concerns removal of particles in the 44-to-88 micron size range from roughly textured asphalt or concrete using a 1.5-inch fire nozzle with a 5/8-inch bore. Nozzle pressure was 75 pounds per square inch, and the initial contaminated mass loading was 5 grams per square foot. Under these conditions, the amount of water used was 0.22 gallon per square foot, which is equivalent to a 0.35-inch coverage of water. The reported "working rate" was 450 square feet

per hour, but the effective rate--taking into account support services and 20 minutes to disconnect from one hydrant, move, and reconnect to the next--was 270 square feet per minute. This works out to 16,216 square feet per hour, which is in reasonable agreement with the unadjusted rate reported from Spokane Community College. This figure, therefore, includes the 20 minutes.

Owen et al. suggested additional adjustments to compensate for fatigue. Coverage rates should be reduced by 20 percent where: a) 4-hour shifts are planned for persons obviously not conditioned to physical labor, or b) 8-hour shifts are planned for experienced and properly conditioned crews. No adjustment was recomnended for well-trained and conditioned personnel working 4-hour shifts. Since calculations in this document are based on 8-hour shifts, the coverage rate needs to be adjusted. Further adjustment is necessary for one hour per 8-hour shift lost to exigencies of the hazardous conditions. With these adjustments and conversion to metric units, we get:

$$16{,}216\ ft^2/hr \times 0.80 \text{ fatigue adj.} \times 7/8 \text{ adj.} \times 0.093\ m^2/ft^2$$
$$= 1056\ m^2/hr$$

This figure is quite close to the adjusted rate calculated for Spokane Community College. The average of the two rates is 1017 square meters per hour.

Table A.1.3.2 summarizes the rate and cost information for manual firehosing. Labor comprises 85 percent and equipment 15 percent of the operation.

Estimating the cost of high-pressure hosing of pavement using fire equipment such as pumpers and tankers is difficult because fire fighting

TABLE A.1.3.2. Summary of Manual Firehosing Information

Source	Water Applied (in.)	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Equipment
Spokane Com. Coll.	0.64	977	0.021	0.018	0.003
Owen et al.	0.35	1056	---	---	---

equipment is used for emergencies, not continuous operation. Moreover, the personnel which use the equipment are specially trained for emergency operations. This sort of usage is much different from the relatively slow, methodical, and repetitive operation of hosing down streets as might be done following a nuclear reactor accident. The major differences as they would bear on costs are apparent. Equipment and personnel would be in near-continual use. This would have the effect of lowering the average cost per hour of operation of both labor and equipment. Further, it would not be necessary to employ such highly trained and highly paid people as firefighters. For these

reasons, the information provided by fire department sources occasionally needs to be adjusted by a significant amount.

Pump trucks commonly have the ability to pump 100 gallons per minute at 100 pounds per square inch. However, the equipment can be adjusted to put out less water at higher pressures or more water at lower pressures. Pump trucks themselves generally have a 500-gallon tank capacity. At a pump rate of 100 gallons per minute, it is clear that pumpers require some additional water supply. The two alternatives for this are i) attachment to a hydrant or ii) use of a shuttle of tanker trucks. Tanker trucks normally have a capacity of 2,000 to 3,000 gallons. Larger capacity water transport vehicles do exist. A pumping rate of 100 gallons per minute would require a tanker-load of water, say, every 30 minutes of pumping. The number of tankers required to keep a pumper supplied will depend on the travel time to and from the water source, the time to refill a tanker, and the length of any interruptions in pumping by the pumper. Here we assume that three tankers per pumper are sufficient.

With respect to the labor requirements for high-pressure hosing of streets, sources associated with fire departments, not surprisingly, responded in terms of standard firefighting crews. Thus, both the Richland, Washington, Fire Chief and the Director of Finance of the Seattle Fire Department indicated that the crew for each pumper should consist of two firefighters and one officer and for each tanker there should be one firefighter. The Chairman of the International Fire Chiefs Association Hazardous Materials Committee recommended four people per pumper and three people per tanker.

Here we assume that with fire hydrants three people with one pumper will be sufficient. The Richland Fire Chief provided labor and equipment costs that have been standardized across Washington State. This standardization was done by the State Fire Chiefs Association for the purpose of interdepartmental billing when one department loans some of its equipment and personnel to a neighboring department for firefighting. At these rates a firefighter costs $15 per hour, an officer $20 per hour, a pumper $85 per hour plus $1.50 per mile, and a 1250-gallon tanker $35 per hour plus $1 per mile. The Seattle Fire Department provided similar labor costs--$15 per hour for a firefighter and $18 per hour for an officer. Both sets of labor costs include salaries and benefits.

The lesser of these two sets of labor cost figures comes to $48 per hour for a three-man crew. As mentioned earlier, for decontimination work it would not be necessary for all workers to have the training, skills, and experience of firefighters. However, some specialized skill would be required for operation of the pumper. For the purposes at hand, we use $48 per hour for the three-man crew. The $85 charged per hour of use for the pumper may overestimate the average hourly cost with continuous operation. Nonetheless, that figure was used here since there was no basis for doing otherwise. Therefore, with hydrants available to supply water to the pumper, the total cost per hour is $133. Labor accounts for 36 percent of the total, and the remaining 64 percent goes for capital, as well as operation and maintenance.

The estimates for the time required to adequately hose a paved surface varied greatly. The Chairman of the International Fire Chiefs Hazardous

Materials Committee indicated that adequate hosing would require 500 gallons for 100 square feet. This is a huge amount of water. It is equivalent to covering all paved surfaces with water to a depth of eight inches. If we assume 16 blocks per mile with streets 40 feet wide, there are 13,200 square feet of street pavement per (linear) block. At a pumping rate of 100 gallons per minute, this coverage would require 11 hours per block.

In contrast, Nowell Patten, of the International Association of Fire Chiefs, estimated 15 to 20 minutes per block, excluding setup time. Close to this estimate was the one from the Seattle Fire Department Research and Development Section. They estimated half an hour for hosing one linear block and ten minutes for moving and setting up for the next block. The Richland, Washington Fire Department source felt that one to two hours per block would be required.

Of course, the length of time for hosing will be at least partially a function of the desired thoroughness, or level of decontamination, to be achieved. Unfortunately, except for Owen et al., the available references for the effectiveness of high-pressure hosing are not clear about the amount of water per surface area used. The coverages reported in Owen et al. range from 0.21 inches to 0.51 inches per pass. In fact, establishing a fixed water coverage per pass is arbitrary since one pass of, say, 1.00 inch of water should have about the same effectiveness as two passes of 0.50 inch of water. Lacking a more definitive standard, the coverage rate used here has been set equal to 0.50 inch. One reason for choosing this relatively heavy coverage is that because moving and setting up at a new location are costly, it is more economical to apply more water in fewer passes than less water in more passes.

Referring to Table 3.1 in Owen et al., we find that a coverage of 0.50 inch (0.31 gallon per square foot) can be applied at an effective rate of 213 square feet per minute. This allows 20 minutes for reconnecting to the next fire hydrant. This rate is equivalent to 1189 square meters per hour. With the final adjustment of one hour per shift for radiation protection measures and reduced productivity, we get 1040 square meters per hour.

The cost per square meter is:

$$\frac{\$133/\text{hr}}{1040\ \text{m}^2/\text{hr}} = \$0.13/\text{m}^2$$

In the event that fire hydrants are not available, it would be necessary to add the cost of three tanker trucks and their drivers. We assume a cost of $17.45 per hour for the drivers. Recalling that the rental rate for a 1250-gallon fire department tanker in Washington is $35 per hour plus $1 per mile, we assume an average hourly cost of $50 per hour per tanker. This accounts for a larger tank capacity and about 10 miles driving each hour. With three tankers and three drivers, the cost of supplying one pumper with water is $202.35 per hour. The additional cost per square meter is:

$$\frac{\$202.35/\text{hr}}{1040\ \text{m}^2/\text{hr}} = \$0.19/\text{m}^2$$

This brings the total cost per square meter to $0.32. The share of the total cost comprised by labor is 26 percent, and that comprised by capital and operation and maintenance is 74 percent.

Standard fire department pump trucks are designed for stationary use. They are generally positioned at a convenient location for firefighting and kept there until the truck is no longer needed for that fire. In contrast, hosing pavement requires forward movement, even if the movement is slow. For this reason, other sorts of equipment were investigated.

Both the Forest Service and airport firefighting units have what is referred to as "pump and roll" equipment--equipment designed to pump water from a nozzle while the vehicle is moving. Unfortunately, for the purposes at hand, this equipment generally has a much too limited tank capacity, often less than 100 gallons.

When posed the question of how to efficiently accomplish a high-pressure hosing of very large areas of pavement, four different sources suggested essentially the same approach. These sources included contacts at the Portland, Oregon, and Wenatchee, Washington, offices of the U.S. Forest Service, at the U.S. Bureau of Land Management Interagency Fire Center in Boise, Idaho, and at Wajax Firefighting Equipment, Seattle, Washington. The method they suggested was to fit a 3,000-gallon tank truck with a pump and a multi-orifice spray-bar. None of the sources indicated that there would be any problem in assembling such a rig. Further, the same basic equipment with some variation in pump size and the spray-bar could be used for low-pressure flushing, high-pressure flushing, very high-pressure flushing, and other applications of liquids to roads. The major difference in equipment for these functions is pump size.

While a 20-horsepower pump can generate a flow rate of 100 gallons per minute at 100 pounds per square inch, the flow rate drops sharply if the same pump is set for 400 pounds per square inch. The result is that a substantially larger pump is required to generate both pressure and volume.

Besides the fact that the same basic equipment configuration can be used for low-, high-, and very high-pressure flushing, equipment of this sort may be immediately available. According to the Forest Service in Portland, heavy construction contractors use and rent this equipment. The Interagency Fire Center said that the military has a large surplus quantity of high-pressure, high-volume trucks for sale.

According to Wajax Firefighting Equipment, a new 3,000-gallon tank truck would cost about $25,000 and the auxiliary equipment would add another $6,000-$8,000 to the cost, bringing the total to something like $32,000. The source added that the General Services Administration estimates the charges for a 1,000-gallon truck-sprayer at $19.60 per hour for operation and maintenance plus $500 per month for charges against capital. On this basis Wajax estimated the comparable charges at $25.00 per hour and $600 per month for a 3,000-gallon rig. At a spray rate of 100 gallons per minute, the truck can spray for 30 minutes before refilling. Refilling time depends on the method. A gravity feed from an elevated tank would take only two to four minutes. A hydrant with

a four-inch fitting could fill the tank in 10 minutes, while refilling from a pool with a booster pump would take 20 minutes. In addition, there would be travel time to and from the fill site. Assuming 20 minutes for filling and traveling plus one hour per shift for equipment and personnel radiation decontamination, there are 4.2 hours for spraying. This gives 8.4 loads of 3,000 gallons each applied per shift, ignoring the problem of fractional tanker loads (shift length could be adjusted).

Assuming 43 shifts per month and 8 hours per shift, the hourly charge was figured as the sum of the monthly rental rate plus the hourly operation and maintenance charge plus the operator's salary:

$$\frac{\$600/\text{mo}}{43 \text{ shifts} \times 8 \text{ hrs/shift}} + \$25/\text{hr} + \$17.45/\text{hr} = \$1.74 + \$25 + \$17.45$$

$$= \$44.19/\text{hr}$$

Using these cost figures, labor comprises about 39 percent, capital 4 percent, and operation and maintenance 57 percent.

Given the spray rate of 100 gallons per minute over a ten-foot width, the truck's speed is inversely related to the amount of water applied to the pavement. For an average of half an inch of water, the truck's speed would be 0.36 miles per hour. For twice as much water, an inch, the speed would be half that--0.18 miles per hour. On the other hand, looking at the coverage as determined by the speed, a speed of one mile per hour gives a coverage of 0.18 inches of water. Using this one mile per hour speed, the total coverage per shift would be:

$$1 \text{ mi/hr} \times 4.2 \text{ spraying hrs} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$= 20{,}624 \text{ m}^2/\text{shift}$$

The average coverage per shift hour is, therefore, 2,578 square meters. Dividing this into the cost per hour yields a cost per square meter of $0.017.

The Bureau of Land Management Interagency Fire Center provided information on a 9,000-gallon capacity tractor-trailer rig. The cost of this equipment is shown in Table A.1.3.3. These figures are considerably higher than those supplied by Wajax for two reasons. The tank capacity is triple that represented by the Wajax data. Also, the pump in the BLM equipment is much larger. Note that the pump is mounted on a separate trailer. While it could be mounted on the truck frame itself, the BLM source said that this arrangement would facilitate using the truck's own pump to fill the tank if filling were to be done from a pond.

The price of the pump varies with the model selected. This source provided the following prices for various Hale brand pumps. The flow rates shown in Table A.1.3.4 are all given at 150 pounds per square inch pressure.

TABLE A.1.3.3. Firehosing Equipment Costs, Bureau of Land Management Interagency Fire Center

Item	Price
Tractor	70,000
Trailer (9,000 gal Brauhaus)	30,000
Spreader bar, installed	5,000
Pump	11,550-13,800
Add'l trailer for pump	4,340
Total	$120,890-123,140

TABLE A.1.3.4. Flow Rates and Prices for Hale Pumps

Hale Pump Model	Rate (gal/min)	Price (1982 $)
FB50-F300	700	$11,550
FB50-C318	850	12,475
FB75-C318	850	12,750
FB75-F460	750	13,500
FB100-F460	1100	13,800

The price differences are due to valves and other fittings as well as flow rates. A precise evaluation of the proper choice of pump would involve weighing the values of the marginal products of the various inputs. Lacking the ability to do that, it can be noted that the last and most expensive pump on the list gives the highest pump rate per dollar. Also, the marginal cost for additional pump capacity generally declines for these models as capacity increases. As a result, further calculations will be made based on the largest of the pumps shown on this list.

The source gave the hourly operation and maintenance cost at $20 per hour. This figure is not consistent with the higher figure for the smaller rig described by Wajax. It seems more likely that the BLM figure is too low rather than the Wajax figure too high. Arbitrarily, we assume an hourly operation and maintenance charge of $35. The monthly capital equipment charge will be more or less proportional to the total purchase price. Using the Wajax figures to estimate the monthly equipment charge on this basis, we get $2300.

As in the previous case, the cost per hour comes from summing the average capital cost, the operation and maintenance cost, and the operator's salary:

$$\frac{\$2,300/\text{mo}}{43 \text{ shifts} \times 8 \text{ hrs/shift}} + \$35/\text{hr} + \$17.45/\text{hr} = \$6.69 + \$35 + \$17.45 = \$59.14$$

Of this amount, labor comprises 30 percent, capital 11 percent, and maintenance and operation make up the remaining 59 percent.

At a pump rate of 1,100 gallons per minute, the entire 9,000-gallon tank capacity will be expelled in a little over 8 minutes. This would permit the truck to drive faster while spraying. Here we assume 30 minutes total time for refilling, including travel to and from the fill site. This assumes a faster fill rate than for the 3,000-gallon truck, which would be likely if this larger-size equipment were used and higher-capacity pumps were purchased. Over a seven-hour period this equipment should average about 11 tank loads applied, with about 1.5 hours actual spraying time.

Again, the vehicle's speed and the amount of water sprayed per unit area are inversely related. Since the pump rate is 11 times that of the 100 gallon per minute equipment, the same coverage can be attained at a vehicle speed 11 times faster. Thus, for a coverage of half an inch, vehicle speed would be four miles per hour. This equipment would get the same coverage (0.18 inches) at 11 miles per hour that the 100 gallon per minute pump would produce at one mile per hour.

Assuming a vehicle speed of ten miles per hour (coverage of 0.20 inches), the area covered per shift would be:

$$10 \text{ mi/hr} \times 1.5 \text{ hrs spraying} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 = 73{,}656 \text{ m}^2$$

The average coverage per shift hour would be one-eighth of this amount, or 9,207 square meters. The cost per square meter works out to:

$$\frac{\$59.14/\text{hr}}{9207 \text{ m}^2/\text{hr}} = \$0.006/\text{m}^2$$

The Portland office of the U.S. Forest Service advised that a 3,000-gallon capacity tank truck with pump and spray bar would cost about $68,000 new. The performance specifications for this equipment were essentially the same as those described by Wajax Firefighting equipment. The only difference is the higher capital cost. This source was not able to provide additional cost data. Since there was no other new information from this source, apart from the purchase price, the same calculations as were done with the Wajax data were repeated. Only the capital cost figure was changed.

The monthly capital equipment cost was adjusted proportionately to the higher purchase price. This raised the hourly charge for capital to $3.71. Proceeding with exactly the same calculations as for the Wajax data, we get a total hourly cost of $46.1-6, of which labor comprises 38 percent, capital 8 percent, and operation and maintenance 54 percent. The cost per square meter is $0.018 at the same rate of 2578 square meters per hour.

Means' Building Construction Cost Data 1982 provided information that can give an indication of the cost of the operation. The lease and operating costs of a truck tractor and water tank trailer with engine-driven discharge

are listed. A detailed description of this equipment is not available, so it is assumed that even if this equipment is not suitable for high-pressure pavement washing, the costs are not greatly different from the costs of proper equipment.

Four types of truck tractors are listed, differing in load capacity. The choice of tractor is therefore determined by the choice of trailer. Here there are two choices, one with a 5,000-gallon capacity and the other with a 10,000-gallon capacity. The truck tractors that appear to be appropriate for these trailers are, respectively, one with 195 horsepower and a 30-ton capacity, and one with 24.0 horsepower and a 45-ton capacity. The costs of these two rigs, as printed in Means, are shown in Table A.1.3.5.

TABLE A.1.3.5. Means Cost Data for Firehosing Equipment

	Hourly Oper. Cost	Rent per Month
30-ton tractor	$ 8.10	$1675
5,000-gallon trailer	8.40	1975
Total	$16.50	$3650
45-ton tractor	$12.25	$2400
10,000-gallon trailer	9.95	2875
Total	$22.20	$5275

With two shifts per day, there are 336 hours per month. Dividing by this number gives an hourly rental cost for the smaller equipment set-up of $10.86 and $15.70 for the larger one. Total hourly equipment cost is, then, $27.36 for the 5,000-gallon arrangement and $37.90 for the 10,000-gallon arrangement. Added to each of these is the $19.75 hourly labor cost for a heavy-truck driver.

The coverage rates for these two truck-trailer rigs are estimated in a manner similar to the previous estimates. At an assumed discharge rate of 100 gallons per minute, the 5,000-gallon tank would provide water for 50 minutes. If refilling takes 30 minutes and there are seven hours per eight-hour shift available for spraying, then 5.25 tank loads per shift could be applied. With 50 minutes spraying time per load, the total spraying time would be 4.375 hours per shift. Total surface coverage would be

$$1 \text{ mi/hr} \times 4.375 \text{ hrs. spraying/shift} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide}$$
$$\times\ 0.093\ m^2/ft^2 = 21{,}483\ m^2/\text{shift}$$

Hourly coverage would be one-eighth of this amount, or 2685 square meters.

For the 10,000-gallon truck-trailer setup, one tankload would provide 100 minutes of spraying at the 100 gallons per minute rate. If refilling takes 40 minutes, then a complete cycle of refilling and spraying will take two hours

and 20 minutes. With seven production hours per shift, three tank loads will be sprayed, giving a total spraying time of five hours. Coverage in one shift will be

$$1 \text{ mi/hr} \times 5 \text{ hrs} \times 5280 \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 = 24{,}552 \text{ m}^2$$

One-eighth of this amount, 3069 square meters, is the averaqe hourly coverage.

Having the coverage rate, it is easy to calculate the cost per square meter. They are as shown in Table A.1.3.6.

TABLE A.1.3.6. Summary of Means Cost Data

Tank Capacity	Rate (m^2/hr)	Cost (1982 \$/m^2)		
		Total	Labor	Equipment
5,000 gallon	2685	0.0176	0.0074	0.0102
10,000 gallon	3069	0.0187	0.0064	0.0123

Table A.1.3.7 summarizes the foregoing information regarding the high-pressure hosing of pavement. One thing that is apparent is that the cost estimates cover a wide range. The highest cost estimates were those using fire department data. Using fire department pump trucks tends to be a slow method which also requires more equipment and more personnel per unit area. Of the methods presented, clearly the simplest one is to supply workers with hoses and little else. This method is quite practicable from a cost standpoint, too, as long as hydrants or high-pressure water mains are accessible. The BLM cost figure is significantly lower than all others. This low cost is primarily the consequence of utilizing a high output pump. Since Wajax, the Portland Forest Service office, and the Wenatchee Forest Service office all specified the same equipment and only the Bureau of Land Management Interagency Fire Center specified this high-volume equipment, there is a question as to whether the high-volume equipment is as common and as readily available. If this equipment is readily available, then it would be the preferred choice. If hydrants are available and the application of a high-volume of water is deemed desirable, then manual hosing would probably be the choice. In cases where neither high-pressure hydrants nor the BLM-specified equipment is readily available, as may be likely, the Wajax-Forest Service figures become the preferred choice. All non-labor costs are included under the equipment heading.

A representative cost would appear to be about \$0.018. Rates and cost shares are more widely dispersed. In general, the Wajax and the Means figures for the 5,000-gallon equipment seem fairly reliable and not extreme; they were taken as representative.

A.1.4 Very High-Pressure Water Flushing

The porosity of asphalt and concrete will result in some radioactive particles being inaccessible to methods which otherwise have good removal

TABLE A.1.3.7 Summary of High-Pressure Water Cost Data

Method and Source	Vehicle Speed (mi/hr)	Amnt. Water Applied (in.)	Rate (m^2/hr)	Cost (1982 $/$m^2$)		
				Total	Labor	Equipment
Manual firehosing						
Spokane Comm. Col.	--	0.64	977	0.021	0.018	0.003
Owen et al.	--	0.35	1056	--	--	--
Pumper w/ hydrant						
Var. fire depts	--	0.50	1040	0.13	0.05	0.08
Pumper w/ tankers						
Var. fire depts	--	0.50	1040	0.32	0.08	0 24
Tanker w/ pump						
Wajax	1	0.18	2578	0.017	0.007	0.010
BLM	10	0.20	9207	0.006	0.002	0.004
Forest Service	1	0.18	2578	0.018	0.007	0.011
Means - 5,000 gal.	1	0.18	2685	0.018	0.007	0.011
Means - 10,000 gal.	1	0.18	3069	0.018	0.006	0.012
Representative	1	0.18	2685	0.018	0.007	0 011

efficiencies. One way to dislodge and remove particles which have become embedded in the pavement surface or have penetrated into crevices below the surface is to use a very high-pressure water wash. At pressures around 400 pounds per square inch there is a good scouring action. However, in some cases water at this pressure may actually erode and break up some asphalt pavements.

According to Wajax Firefighting Equipment in Seattle, Washington, the most efficient way to accomplish a very high-pressure water scouring of pavement seems to be to use an equipment arrangement similar to that described previously in the discussion about high-pressure (100 pounds per square inch) water flushing. A tank truck with a capacity of, say, 3,000 gallons is fitted with a pump and a spray bar. With this setup, the truck can spray a ten-foot wide swath of pavement as it moves forward.

The major difference between the equipment required for the 100 pounds per square inch wash and the equipment required for the 400 pounds per square inch wash is the pump size. In order to maintain a flow rate of 100 gallons per minute at this higher pressure, a large pump driven with a V6 or V8 engine is necessary. Such a pump may be towed behind the truck on its own trailer or mounted on a larger truck frame. A 5-ton truck chassis would be required for the tank, pump, spray bar, and necessary auxiliary equipment.

The pump will cost about $20,000 and the truck about $35,000, for a total of $55,000. Wajax suggested monthly lease payments of $600 for equipment costing $32,000. Using a proportional relationship, the monthly capital charge for this equipment is about $1030. With slightly less than an average of 22 working days per month and two shifts per day, this works out to:

$$\frac{\$1030/\text{mo}}{43 \text{ shifts} \times 8 \text{ hrs/shift}} = \$3.00/\text{hr}$$

Wajax did not provide an hourly operation and maintenance cost for this equipment, but with the larger pump and pump engine we can assume it will cost more to run than equipment detailed in the section about high-pressure water flushing. Here we assume an hourly cost of $35.00. In addition, there are labor costs of $19.75 per hour for a heavy-truck driver.

Referring to Means' Building Construction Cost Data 1982, comparable cost figures can be derived. The basic equipment for very high-pressure water scrubbing of pavement would include the 5,000-gallon truck-trailer rig described in the previous section. To this would be added a high-pressure pump. On page 309, Means lists the costs of various diesel and electric firepumps, but it is not clear which, if any, of these would be appropriate. Perhaps the closest match between these pumps and the requirements for pavement washing would be met by modifying either the 85- or 118-horsepower pumps for higher-pressure and lower-volume output. These pumps cost about $30,000 each. On page 14, a 200-horsepower high-pressure pump is listed along with its hourly operating cost ($5.60) and the monthly lease rate. The lease rate is given as $1300 for the first month, $1180 for the second month, and $900 for the third month. Assuming that these costs are close to the costs for the proper pump for this application, the cost per square meter can be calculated. We estimate

the monthly rental charge for the pump with trailer and other incidental equipment at $1150. This comes to about $3.40 per hour. Adding the operating cost gives $9.00 per hour more for the equipment for very high-pressure (400 pounds per square inch) water spraying compared with the high-pressure (100 pounds per square inch) spraying. This brings the total hourly equipment cost to $36.36.

There is little information about how much water should be used. The Wajax source said that a vehicle speed of from four to six miles per hour should result in good removal. This would result in a surface coverage of about 0.04 inches when the 100 gallons per minute is spread over a width of ten feet. Other sources on decontamination effectiveness were unclear about how much water should be applied to achieve any particular level of effectiveness. The coverage assumed here was 0.18 inches, the coverage resulting from a vehicle speed of one mile per hour. This is at the low end of the amounts of water reported in Owen et al.

With vehicle speed and refilling times about the same as for high-pressure spraying, we can calculate the costs on a square-meter basis by straightforward division. This information is presented in Table A.1.4.1. Note, however, that because water at pressures as high as 400 pounds per square inch may erode and break up asphalt pavement surfaces, it may be necessary for the spray truck to move faster than one mile per hour on asphalt.

TABLE A.1.4.1. Cost Data for Very High-Pressure Water Spraying

Source	Rate (m^2/hr)	Cost Basis	Cost (1982 $) Total	Labor	Equipment
Wajax	2685	$/hr	54.75	19.75	35.00
		$/$m^2$	0.0204	0.0074	0.0130
Means	2685	$/hr	56.11	19.75	36.36
		$/$m^2$	0.0209	0.0074	0.0135
Representative	2685	$/hr	55.43	19.75	35.68
		$/$m^2$	0.0206	0.0074	0.0132

A.1.5 Foam

Acid-based foams rely on maintaining a concentration gradient through the foam's thickness to pull the contamination out of the surface by reverse osmosis. Turco Products, a Division of Purex Corporation, in Carson, California, manufactures chemical bases for such foams. The method they prescribe is to mix the decontamination chemical such as Turco 4512A or Turco 4306D with water. The 4512A comes as a liquid costing $13.00 per gallon and is mixed to a ten-percent solution by volume. The 4306D comes as a powder, sold at $180 for 100 pounds. It is mixed 6 ounces per gallon of water.

The prepared solution is applied by pumping at about 20 to 40 pounds per square inch pressure. The use of a foaming head such as a Dema Model 293 permits mixing with air and Turco 5865 to create a lather-like foam. The Turco 5865 is injected through the detergent supply connection on the foaming head. With the maximum quantity discount, this material costs $6.25 per gallon. It is mixed with the 4512A solution at something like one part foaming agent in ten.

The foam is allowed to remain on the surface for at least an hour and preferably longer. It is then removed with a wet-vacuum and a foam suppressant such as Turco Liquid Lid. This product was not developed as a foam suppressant, but it apparently works better than products that were. A standard mobile vacuumized street sweeper will work for foam pickup. Liquid Lid costs about $10 per gallon.

The prices of the chemicals given here are prices F.O.B. at the Turco plant. Shipping costs will vary according to the distance shipped, of course, and also by the direction shipped, the type of chemical shipped, and the total size of the shipment. Turco estimates shipping charges on the basis of a price scale for different zones. The cost per gallon ranges from $0.60 for shipments going to a zone 1 destination, to $1.20 for shipments destined for locations in zone 6. On the basis of these figures, we assumed an average shipping charge of $1.00 per gallon and $0.10 per pound. This raises the total costs of the chemicals as shown:

TABLE A.1.5.1. Chemical and Shipping Costs for Foam Decontamination

	Costs (1982 $)		
Chemical	Price, F.O.B. Plant	Shipping Cost	Total Price, Shipped
4512A	$ 13.00/gal	$1.00/gal	$ 14.00/gal
4306D	$180.00/cwt	$0.10/lb	$190.00/cwt
5865	$ 6.25/gal	$1.00/gal	$ 7.25/gal
Liquid Lid	$ 10.00/gal	$1.00/gal	$ 11.00/gal

The diluted 4512A solution will cover about 200 to 250 square feet. At $14.00 per gallon, this is equivalent to $0.0753 per square meter using a coverage of 200 square feet per gallon. The 4306D solution has a similar coverage so that the cost per square meter is $0.0363. Since this is less costly than the 4512A, further cost calculations are based on use of 4306D. The foaming agent 5865 mixed 1:10 with the 4306D solution will cover 2000 square feet per gallon. This yields a figure of $0.0390 per square meter. One pint to 1 quart of Liquid Lid is adequate for 20 gallons of 4306D solution. At one quart to 20 gallons, one gallon of Liquid Lid will be required for every 1488 square meters. The cost per square meter is, therefore, $0.0074. The total chemical costs per square meter are shown in Table A.1.5.2.

TABLE A.1.5.2. Total Chemical Costs for Foam Decontamination

Chemical	Cost (1982 \$/m^2)
4306D	0.0363
5865	0.0390
Liquid Lid	0.0074
Total	0.0827

The foam could be applied with equipment very similar to the tank truck with pump and spray bar arrangement used for high-pressure water washing of pavement. For the purpose of applying foam, the spray bar or row of nozzles would be mounted across the rear bumper rather than the front. Since lower pressure and lower volume pumping are required, a smaller pump could be used. On the other hand, the nozzles must be such that they will mix the foaming agent with the acid-based decontamination chemical. Such nozzles must be manually set, but once set they seldom need readjustment. A ten-foot row of nozzles may require another person per truck in addition to the driver. Finally, separate tanks must be provided for the foaming agent and the decontaminant.

We estimate the capital cost and the operation and maintenance cost of this equipment to be ten percent higher than required for a high-pressure water wash. Also, we assume two people per truck will be necessary. Using the representative cost data described in the section on high-pressure water washing of pavement, we get \$30.11 per hour for equipment. With two workers, the hourly labor cost comes to \$39.50. The total hourly cost is \$69.61.

If the truck applies foam at five miles per hour, the proper pump rate is 22 gallons per minute. At this rate a tank load will be sprayed in about three hours and 45 minutes. Estimating half an hour for refilling, about 1.5 tank loads can be applied in the seven production hours per eight-hour shift, the extra hour being set aside for equipment and personnel decontamination measures. This means that in an eight-hour shift there will be 5.6 hours of actual foam application time. The coverage will be:

$$5.6 \text{ hrs} \times 5 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2$$
$$= 137{,}491 \text{ m}^2/\text{shift}$$

The average coverage per shift-hour will be 17,186 square meters. The cost per square meter will be:

$$\frac{\$69.61/\text{hr}}{17{,}186 \text{ m}^2/\text{hr}} = \$0.0041/\text{m}^2$$

As for removing the foam, mobile vacuumized street sweepers can be used. Their cost was calculated separately in Section A.l.l dealing with vacuumized street sweepers. The rate of surface coverage for a vacuumized street sweep is

one-half the rate of foam application. Thus, for each spray truck there would be two vacuumized street sweepers. The rate for the entire operation would be 17,186 square meters per hour.

Table A.1.5.3 summarizes the costs of chemicals, application, and removal. The last line of the table presents the combined costs based on these

TABLE A. 1.5.3. Cost Summary of Foam Decontamination of Pavement

Item	Rate (m^2/hr)	Cost (1982 $\$/m^2$) Total	Labor	Eauiument	Materials
Chemicals					
4306D	--	0.0363	--	--	0.0363
5865	--	0.0390	--	--	0.0390
Liq. Lid	--	0.0074	--	--	0.0074
Total Chem.	--	0.0827	--	--	0.0827
Application	17,186	0.0041	0.0023	0.0018	--
Removal (2x)	8,632	0.0043	0.0021	0.0022	--
Total All Items	17,186	0.0911	0.0044	0.0040	0.0827

data. According to these figures, the great preponderance of cost lies with the chemicals.

A.1.6 Strippable Coating

Several manufacturers produce what is referred to as strippable (or peelable) coatings. These coatings can be sprayed on with a non-aspirated spray to a particular thickness. After drying, the material can be peeled off like cellophane tape. In addition to coatings that are physically or mechanically strippable, there are related coatings that can be removed with a chemical solution.

This material can perform three desirable functions. The first is that the material works as a fixative. On essentially any surface, the coatings will hold the contamination in place. The second function is that in removing the coating, much of the surface contamination is removed as well. The third function of this product is that it can be used to protect surfaces from contamination. By applying a coating before exposure to radiation, the radioactive particles can be prevented from becoming embedded in the surface. This last function is currently the most important one from a commercial standpoint. So-called "Grafitti Shield" is a chemically strippable coating.

The method of application can vary as long as a non-aerosol spray is used. Layers can be built up to the necessary thickness even if successive layers are allowed to dry before the application of the next layer.