the soil. Ground application to the trees is performed with an orchard blast sprayer, while a weed sprayer is used to apply a fixative to the soil.

Defoliation is performed to remove contaminated tree leaves. This procedure is accomplished by aerially spraying a defoliant. It should be noted that if a defoliant is applied during the growing season, then the trees are likely to be killed.

Soil scraping without removing the trees uses two workers with shovels to remove dirt from the base of the trees. A small front-end loader scrapes, removes, transports the soil, and loads it into dump trucks. This procedure requires extra care not to damage the trees or their roots.

Shallow plowing or discing helps contaminants migrate down into the soil. Care must also be taken with this activity to avoid root damage.

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

In addition to defoliation, a significant proportion of the radioactive particles on the trees can be removed with radical pruning. This involves cutting back the branches to the maximum extent possible without killing the trees. This would, however, result in lowered property values because several years of crops would likely be lost. Operations on orchards are summarized in Table 2.3.

2.4.1.3 Vacant Land

Vacant land refers to undeveloped land with grass and brush plant cover. It is treated with operations that are in most cases similar to those used on agricultural fields.

A fixative is applied to vacant land using a spray distributor tank truck. Either Coherex or lignosite appears to be an appropriate fixative choice. The costs reported here are for Coherex.

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

Scraping, watering, leaching, plowing, deep plowing, and covering with clean soil are all essentially the same operations as those described for

Table 2.3. Summary of Representative Cost and Productivity Data for Decontamination Operations on Orchards

Operation	Rate (m^2/hr)	Cost (1982 $/$m^2$)			
		Total	Labor	Equipment	Material
Water	3,541	0.0014	0.0014	--	--
Fixative, aerial application	7,467	0.371	0.019	0.262	0.090
Fixative, ground application to trees and ground	280	0.213	0.027	0.047	0.10
Defoliate	8,331	0.0146	0.0006	0.0015	0.0105
Leach, $FeCl_3$	2,545	0.0338	0.0034	0.0030	0.026
Scrape without removing trees	148	0.658	0.496	0.162	--
Plow	8,047	0.0044	0.0006	0.0018	--
Remove and replace	98	0.385	0.129	0.125	0.122
Radical prune	340	0.071	0.029	0.042	--
Cover with soil, trees removed	549	0.371	0.106	0.265	--
Cover with soil, trees not removed	55	1.94	1.38	0.56	--
Scrape with trees removed	875	0.31	0.13	0.18	--

agricultural fields. Note, however, that terrain and soil conditions may greatly affect the cost, rates, and even the ability to accomplish these operations. Table 2.4 summarizes the data for decontaminating vacant land.

Table 2.4. Summary of Representative Cost and Productivity Data for Vacant Land Decontamination Operations

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

2.4.1.4 Wooded Land

Wooded land is generally characterized by difficult access. Lignosite is an appropriate choice of fixative and is applied from the air. Even if the trees are cut down, the area is not usually accessible to heavy equipment because of the remaining stumps. The mechanized scraping operation here includes grubbing with front-end loaders prior to soil removal. Grubbing is a term referring to removal of stumps.

If the trees or stumps are not removed, then scraping is performed manually with laborers equipped with shovels and wheelbarrows. This is a very costly endeavor, and it is appropriate only where a large premium is placed on saving the trees. It is also necessary to cover the ground manually with clean soil if the trees are not removed. Operations in wooded areas are summarized in Table 2.5.

2.4.1.5 Asphalt Streets and Roads

A variety of decontamination techniques can be applied to paved surfaces. These techniques include vacuuming, and applications of water, foam, and strippable coating.

Vacuuming. Mobile vacuum street sweeping, as done by municipal public works departments, airports, and highway departments, is a practical technique for removing radioactive contaminants from pavement. Even though the decontamination efficiency of vacuuming streets is lower than for most other operations on streets, the relative cost per sq meter of area covered is so low that it would be used alone or in conjunction with other procedures in essentially all pavement decontamination methods.

Table 2.5. Summary of Representative Cost and Productivity Data for Wooded Land Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Fixative, aerial	5,600	0.495	0.025	0.350	0.120
Defoliate	5,554	0.0220	0.000	0.0023	0.0158
Clear	266	0.802	0.469	0.333	--
Grub and scrape	656	0.59	0.23	0.36	--
Hand scrape	4	4.62	4.36	0.25	--
Cover, cleared land	549	0.371	0.106	0.265	--
Cover by hand	6	3.24	2.95	0.29	--

The reported cost figures for vacuuming range from $0.0020 to $0.0057 per sq meter, with $0.0043 being a representative estimate. Subsequent applications with a vacuum over the same surface are likely to cost somewhat less per unit area than the first pass, though they will also be less effective.

The rate of surface treatment is highly variable, with sources reporting rates from 7,177 to 29,462 sq meters per hour. A rate of 8,632 sq meters per hour is a reasonable expectation. For smaller paved areas or areas with restricted access, it may be necessary to use other equipment such as an industrial parking lot vacuum.

Low-Pressure Water Wash. Washing paved surfaces with water reduces the committed individual dose from the inhalation/external pathway by about 95/85 percent. Water achieves its effectiveness because many radioactive particles solubilize readily in water. Water also has the ability to reach into crevices, which might shield the contaminants from the air blasts of a vacuumized street sweeper or from other mechanical decontamination methods.

The least costly way to carry out a water wash of this sort is to employ common mobile street flushers. The unit cost for this treatment is about $0.0013 per sq meter. One reason the unit cost is so low is that not only do these machines move along at an average speed of over five km per hour, but they can flush half a street width, six meters, at a time.

While this method is cost-effective in reducing pavement contamination, it has a possible drawback that could greatly limit or even prevent its use. This problem concerns the resulting contaminated water. If there are curbs and storm drains, it may be desirable or acceptable to allow the contaminated water to drain into the storm sewer system. The hazard of radiation in underground mains to people on the surface is significantly mitigated by the shielding of the intervening pipe, soil, and pavement. The storm drain system can also serve as a mechanism to gather the contaminated water from various locations to a central site where the water could be treated or stored. In the absence of storm drains, an option is to let the water run off the pavement and percolate into the soil. However, because of the potential threat to subterranean water supplies or for other reasons, it may be necessary to prevent seepage of the contaminated water.

The issue of disposal of contaminated water bears on all of the water-using decontamination techniques including those applied to roofs and lawns. Indeed, even rain could result in large volumes of contaminated water. A thorough treatment of this issue is beyond the scope of this study.

High-Pressure Water. Hosing paved surfaces with water at pressures in the range of from 25 to 40 kg per sq cm adds significant scouring action to

the solubilizing attribute of water. However, the pressure can also act to drive the contaminants further into the pavement.

The way in which a high-pressure wash of pavement is performed depends primarily on the facilities available. If fire hydrants on high-pressure water mains are available, a relatively inexpensive way to carry out this procedure is simply to equip teams of two or three individuals with a long length of firehose. After hosing all pavement around the hydrant within the reach of the hose, they move on to the next hydrant. The estimated cost of this method is $0.021 per sq meter.

Where no hydrants or high-pressure water mains are accessible, fire department equipment can be used to boost the water pressure and, if necessary, to transport water to the hosing site. However, the accumulated cost data indicate that this is a costly operation. Even if an on-site water supply is available, using a pumper truck to provide the required water pressure raises the cost per area about sevenfold over the manual hosing method just described. If tanker trucks to supply water to the pumper trucks are also required, the cost will rise to about $0.32 per sq meter.

A third method is to equip tanker trucks with a pump and a spray bar. This allows a single piece of equipment to hose a swath three meters wide while moving forward. Even with nearly half the time spent refilling the tanker, the cost of this method is comparable to that of manual hosing. This method is the basis for deriving representative cost and rate figures. With an application of about 0.5 cm of water to the road, the cost per sq meter is $0.0176, and the rate of surface coverage is 2,685 sq meters per hour.

Very High-Pressure Water. Greater scouring and, therefore, greater removal of embedded radioactive particles can be achieved with a very high-pressure blast of water. Very high pressure refers to a pressure of about 135 kg per sq cm. Higher pressures tend to erode the pavement.

Fire equipment pumps are customarily set at around 35 kg per sq cm, but they can be configured to pump at four times that pressure. However, in doing so the volume of water drops sharply. In order to maintain an adequate flow of water at very high pressure, it is necessary to use a large pump powered by a six- or eight-cylinder engine. The pump is mounted on or towed behind a tanker truck equipped with a spray bar. This permits the truck to spray a path one lane wide while driving forward. To apply enough water per unit area, the truck's speed would be about 1.5 km per hour. The cost per sq meter is $0.021.

Foam. An acidic lather-like foam can be an effective method to lift contaminants from pavement. The foam works by inducing reverse osmosis. An acid concentration gradient is maintained through the foam's thickness. As

long as the acidity above is greater than that below, less acidic compounds on the pavement surface will move up into the foam, tending to diminish the acidity gradient.

The foam can be sprayed from a properly equipped tanker truck. After allowing the foam to remain on the pavement for at least an hour, it can be removed with a vacuumized street sweeper. A foam suppressant will allow the sweeper to pick up a large volume of foam by reducing it to a liquid form.

This operation costs in the neighborhood of $0.09 per sq meter. Over 90 percent of the costs are for chemicals. Because the operations of foam application and removal are performed by vehicles, the rate of treatment, over 17,000 sq meters per hour, is relatively high.

With an initial vacuuming, a foam treatment is estimated to reduce the commited individual dose from the inhalation/external pathway by 97.5/91.8 percent.

Strippable Coating. An interesting decontamination method involves spraying or rolling a special chemical solution onto the surface to be decontaminated. After the liquid dries, it can be peeled off like cellophane tape. This strippable coating will take with it much of any loose surface contamination.

Besides their use as a decontaminant, these coatings are also effective as a fixative that can be easily removed and as a protective coating to minimize contamination. For example, before entry into a contaminated area, vehicles can be coated with a peelable coating. This protects the surface of the vehicle from radioactive particles. By peeling off the coating, nearly all of the contamination is removed.

The liquid coating solution can also be sprayed on roads in much the same way as high-pressure water is sprayed on roads from a tanker truck with pump and spray bar. Mechanical removal of the coating using a specially equipped moving vehicle may be feasible. If this efficient removal method can be made operational, the cost per sq meter would be about $1.78. Because the chemicals are so expensive, they account for nearly all the of cost. Removal of the coating by hand would be slow and would raise the cost somewhat, but the percentage increase in the cost would be small.

Besides the cost, there are some additional considerations that need to be mentioned. While there are a number of manufacturers of strippable coatings, it is not clear that there would be sufficient inventories and manufacturing capacity to supply quantities on the scale that would be needed to cleanup from a major reactor accident. Further, practical experience with

this material on large areas of pavement is sufficiently limited so that there is considerable uncertainty as to its removal efficiency in such applications.

Planing. An obvious way to remove the hazard from contaminated pavement is to remove the pavement itself, or at least to remove the contaminated surface. Planing is an operation in which the top surface of the pavement is removed. Planers are machines, varying in width, which remove pavement by abrasion. Planers are used to remove from 1 to 15 cm of pavement surface. In the present case we are only interested in removing 2.5 cm.

While some planers are equipped with a water spray for dust suppression and cooling, a problem with other planers is that they tend to generate much dust which, in a decontamination operation, would include radioactive particles. This dust, then, could lead to significant recontamination of the surfaces just planed unless special measures are taken. Affixing rubber containment skirts around the base of the planing machine and attaching a high-power mobile vacuum intake hose would greatly alleviate the problem. The mobile vacuum would continuously draw in the dust from the grinding. These vacuums normally operate with adequate filtration (down to one micron) so that most of the contaminants would be collected.

Planing with dust control costs around $0.91 per sq meter for an asphalt surface and about $1.09 per sq meter for a concrete surface. The surface after planing is rough but driveable. In most cases a thin (2.5 cm thick) coat of asphalt pavement is applied over the planed road surface.

Thin Surface Coatings. Thin surface coatings such as tack coating, sealer, or road oil can be used as fixatives, which are durable enough to permit road traffic. The costs of these coatings range from $0.30 to $0.54 per sq meter. Of these coatings, road oil has been used successfully as a durable fixative on desert soil at the Nevada Test Site.

Asphalt Pavement Overlay. Applying a layer of asphalt has three major functions. First, acting as a fixative, the asphalt layer will prevent resuspension of radioactive particles. Paving, therefore, has a high efficiency with respect to the inhalation-ingestion pathway. Second, the asphalt provides a certain amount of shielding and thereby is partially effective against external exposure. The effectiveness obviously increases with the thickness of the asphalt layer. A layer 7.5 cm thick will reduce external exposure by about half. Third, paving can be advantageously combined with other operations. For example, the decontamination method of planing followed by paving not only removes, fixes, and shields the radiation, it also restores the pavement surface.

Two asphalt paving operations are considered here. The first is a minimal-thickness asphalt overlay; over an existing asphalt base, the overlay

is 2.5 cm. On a concrete base the minimum thickness is 5 cm. The second paving operation is a medium-thickness pavement overlay. The asphalt layer applied is 7.5 cm thick.

The costs and rates of these operations are usually estimated in terms of the volume of asphalt applied. Thus, covering 100 sq meters with asphalt 2.5 cm thick normally takes the same time as paving 50 sq meters 5 cm thick. The cost of a thin overlay on asphalt roads comes to $2.34 per sq meter, and because of the greater thickness, the cost on concrete roads is double. About 77 percent of the cost is for the asphalt material. Labor and equipment comprise 15 and 8 percent, respectively.

Remove and Replace. For severely contaminated paved surfaces, the most costly operation--pavement removal and replacement--may be indicated. The operation consists of two distinct steps, both with fairly similar production rates. The material cost, however, makes replacement about five times more costly than removal. Replacement involves applying a 15 cm thick layer of pavement.

Tables 2.6 through 2.9 present the basic cost data for the various decontamination operations for paved surfaces.

2.4.1.6 Lawns

Table 2.10 summarizes the data for lawn decontamination operations. Vacuuming is one of the simplest methods for decontaminating lawns. Using an extension hose to a standard vacuumized street sweeper, this method is estimated to reduce the committed individual dose from the inhalation/external pathway by about 30/20 percent for lawns not rained on, and the cost is around $0.19 per sq meter. Rain is likely to render this method much less effective.

Carrying radioactive particles below the soil surface may be an attractive strategy if the subsurface geology prevents contamination of important water supplies or migration to other undesirable locations. The watering of lawn surfaces may achieve a reduction in the committed individual dose from the inhalation/external pathway of about 85/75 percent; it costs only $0.014 per sq meter. The effectiveness of this process is accelerated by using one of a number of chemical agents that have the ability to solubilize radioactive particles. Such chemicals include ferric chloride, EDTA, and calcium chloride. An application with 0.75-cm coverage of a 10 percent solution of ferric chloride will reduce the committed individual dose by about 85/80 percent from the inhalation/external pathway and cost about $0.07 per sq meter. Of this amount, $0.026, or 37 percent of the cost, is for the ferric chloride.

Table 2.6. Summary of Representative Cost and Productivity Data for Asphalt Road Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2)			
		Total	Labor	Equipment	Material
Vacuum	8,632	0.0043	0.0021	0.0022	--
Low-pressure water	26,576	0.0013	0.0007	0.0006	--
High-pressure water	2,685	0.0176	0.0074	0.0102	--
Very high-pressure water	2,685	0.0206	0.0074	0.0132	--
Foam	17,186	0.0911	0.0044	0.0040	0.0827
Strippable coating	4,297	1.7829	0.0094	0.0035	1.77
Planing	750	0.91	0.35	0.56	--
Tack coat	12,890	0.3055	0.0035	0.0024	0.2996
Sealer	1,933	0.54	0.02	0.01	0.51
Road oil	12,890	0.326	0.008	0.008	0.31
Pave with 2.5 cm asphalt	453	2.34	0.35	0.19	1.81
Resurface	453	3.25	0.70	0.75	1.81
Pave with 7.5 cm asphalt	151	7.05	1.05	0.57	5.43
Remove and replace	71	15.40	2.68	3.32	9.40

Another lawn surface decontamination operation involves close mowing with bagging and removal of cuttings. This relatively simple method is estimated to reduce the committed individual dose from the inhalation/external pathway by 65/65 percent at a cost of \$0.147 per sq meter.

Table 2.7. Summary of Representative Cost and Productivity Data for Concrete Road Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2)			
		Total	Labor	Equipment	Material
Vacuum	8,632	0.0043	0.0021	0.0022	--
Low-pressure water	26,576	0.0013	0.0007	0.0006	--
High-pressure water	2,685	0.0176	0.0074	0.0102	--
Very high-pressure water	2,685	0.0206	0.0074	0.0132	--
Foam	17,186	0.0911	0.0044	0.0040	0.0827
Strippable coating	4,297	1.7829	0.0094	0.0035	1.77
Planing	625	1.09	0.42	0.67	--
Tack coat	12,890	0.3055	0.0035	0.0024	0.2996
Sealer	1,933	0.54	0.02	0.01	0.51
Road oil	12,890	0.326	0.008	0.008	0.31
Pave with 5 cm asphalt	227	4.70	0.70	0.38	3.62
Resurface	227	5.79	1.12	1.05	3.62
Pave with 7.5 cm asphalt	151	7.05	1.05	0.57	5.43
Remove and replace	171	19.62	2.48	3.77	13.37

Table 2.8. Summary of Representative Cost and Productivity Data for Other Asphalt Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2)			
		Total	Labor	Equipment	Material
Vacuum	4,316	0.0086	0.0042	0.0044	--
Low-pressure water	13,288	0.0026	0.0014	0.0012	--
High-pressure water	1,342	0.0352	0.0148	0.0204	--
Very high-pressure water	1,342	0.0412	0.0148	0.0264	--
Foam	8,593	0.0995	0.0088	0.0080	0.0827
Strippable coating	2,148	1.7978	0.0188	0.0070	1.772
Planing	375	1.82	0.70	1.12	--
Tack coat	384	0.46	0.16	--	0.30
Sealer	91	1.04	0.41	0.12	0.51
Road oil	6,445	0.342	0.016	0.016	0.31
Pave with 2.5 cm asphalt	227	2.89	0.70	0.38	1.81
Resurface	227	4.71	1.40	1.50	1.81
Pave with 7.5 cm asphalt	77	8.67	2.10	1.14	5.43
Remove and replace	35	21.40	5.36	6.64	9.40

Application of a fixative improves the effectiveness of operations involving removal, such as close mowing and lawn resodding. The nature of lawns makes fixing difficult, and it may be necessary to use a messy material such as road oil to be effective. The cost of road oil was used in estimating

Table 2.9. Summary of Representative Cost and Productivity Data for Other Concrete Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2)			
		Total	Labor	Equipment	Material
Vacuum	4,316	0.0086	0.0042	0.0044	--
Low-pressure water	13,288	0.0026	0.0014	0.0012	--
High-pressure water	1,342	0.0352	0.0148	0.0204	--
Very high-pressure water	1,342	0.0412	0.0148	0.0264	--
Foam	8,593	0.0995	0.0088	0.0080	0.0827
Strippable coating	2,148	1.7978	0.0188	0.0070	1.77
Planing	312	2.18	0.84	1.34	--
Tack coat	384	0.46	0.16	--	0.30
Sealer	91	1.04	0.41	0.12	0.51
Road oil	6,445	0.342	0.016	0.016	0.31
Pave with 5 cm asphalt	113	5.78	1.40	0.76	3.62
Resurface	113	7.96	2.24	2.10	3.62
Pave with 7.5 cm asphalt	75	8.67	2.10	1.14	5.43
Remove and replace	85	25.87	4.96	7.54	13.37

Table 2.10. Summary of Representative Cost and Productivity Data for Lawn Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2)			
		Total	Labor	Equipment	Material
Vacuum	326	0.19	0.13	0.06	--
Water	1,302	0.014	0.013	0.001	--
Leaching	6,400	0.07	0.022	0.022	0.026
Close Mowing	150	0.147	0.129	0.018	--
Fixative	3,545	0.365	0.017	0.038	0.31
Remove and Replace	40	5.43	3.09	0.50	1.84

the cost of this operation. Other fixatives might also be used, since road oil is somewhat more costly than most other fixatives.

As with pavement and roofs, the most effective and most costly decontamination operation for lawns is removal and replacement of the surface; i.e., resodding. With an application of road oil as a fixative, this procedure costs $5.43 per sq meter. The reduction in the committed individual dose from the inhalation/external pathway is estimated at around 98/98 percent.

2.4.2 Water Bodies

Only one surface category has been developed for water bodies, reservoirs. This category is described below.

2.4.2.1 Reservoirs

Developing data for reservoirs is complicated by the difficulty of defining an appropriate measurement unit. To see the problem, we observe that radiological contaminants in a reservoir can exist in three states: as particulates suspended in the water medium, in solution in the water, and mixed with sediment at the bottom. For the first two modes, a volume measurement is appropriate, but for the last mode an area measurement is more appropriate. Because of the wide variation in the shape and dimensions of a reservoir, there is no fixed relationship between the bottom area and water volume.

The compromise that we have made to address this problem is to assume that of the contaminants falling on the water surface, 10 percent will settle to the bottom and mix with the sediment, 25 percent will persist as suspended solids, and the final 65 percent will enter in solution with the water.

One difficulty in determining the appropriate decontamination method rests on the degree of reliance placed on the reservoir as a local water supply. If the reservoir is a major source of an area's water supply with few

acceptable alternative sources, then it may be very important to avoid any decontamination measure that interferes with supplying the local demand. On the other hand, if the reservoir can be taken out of service, then the low-cost operation of draining the reservoir may be very attractive. If alternative water sources are available, using them may be less costly than removing the contaminants from the reservoir. In this case, the alternative sources would be used until contamination levels in the reservoir fell to acceptable levels.

Another consideration concerns the downstream uses of the release flow. If the stream or river fed by the reservoir has significant agricultural, recreational, or consumptive uses, or if the river flows through a populated area, it may be necessary to reduce or even eliminate the discharge of contaminated water from the reservoir. Conversely, if there is little potential risk of damage, draining may again be the preferred decontamination alternative.

Whether the water from the reservoir is also processed in a water treatment facility is relevant, since nearly all such facilities have the capability of removing some or most of the radiological contaminants with little or no additional treatment costs. Procedures include flocculation in which suspended solids and some dissolved materials can be precipitated out. Aluminum hydroxide is used in municipal water treatment systems as a flocculent. In addition, filtration can remove suspended solids.

Four operations for decontaminating reservoirs are examined. Removal efficiency is developed with respect to the percent of contamination removed, rather than in terms of inhalation or external exposure. The efficiency will depend on whether the contaminants are suspended, in solution, or in the sediment. For example, to remove contaminants that are in solution, one might treat the water as it passes through a treatment system. Dredging, on the other hand, would be most effective in removing contaminants from the bottom. Below, we discuss these operations for decontaminating reservoirs.

Drain. The simplest operation is to allow the contaminated water to pass downstream. The feasibility of this operation depends on downstream uses and other considerations, as discussed above.

There are two cost components to draining a reservoir. The first is minimal as it entails simply opening the outflow valves or turning on a pump or siphon system and occasionally monitoring the situation. The second cost component is the downstream damage from the contaminated water. Because the extent of such damage is highly site-specific, this cost is not included in the draining operation. Rather, residual contamination factors can be assigned to the downstream property in DECON (see Section 4.1.1.1), which is an appropriate way to effectively incorporate these costs.

In addition to removing a large portion of the contamination, draining the reservoir may make it feasible to scrape the contaminated sediment from the lake bottom. It might also prove effective to refill and drain the reservoir one or more additional times and then to scrape the bottom.

Scrape. Scraping is performed after a reservoir has been drained. The operation of scraping was discussed in Section 2.4.1.1, as applied to agricultural fields.

Dredge. Contaminated sediment can also be removed from the bottom of the reservoir by dredging. A hydraulic dredge is the preferred equipment. Because for even a modest-sized reservoir, several dredges would be needed to decontaminate the reservoir within a reasonable time, mobilization and demobilization costs are included. We note that inclusion of these is an exception to our normal treatment.

Ion Exchange. The ion exchange process removes solubilized contaminants from the water. The procedure involves passing the water through an ion exchange system, which uses charged resins to produce an effluent of pure water. Through use the resins become saturated with the captured ions and lose their effectiveness. At this point the resins must be replaced or regenerated through a chemical treatment. Regeneration produces a liquid waste in which the radioactive ions have been concentrated.

Ion exchange systems offer one of the few ways to remove dissolved contaminants; the procedure is also quite expensive. The removal efficiency is 67 percent.

The data for decontaminating reservoirs is summarized in Table 2.11.

2.4.3 Structures and Contents

Structures are comprised of several surface categories including roofs, exterior walls and glass, interior walls and glass, and floors. Walls and floors are further broken down by the type of covering material.

2.4.3.1 Roofs

Costs of the various operations for decontaminating roofs are presented in Table 2.12. Vacuuming is not as effective as other methods in reducing the committed individual dose from the inhalation/external pathway--only about 60/50 percent--but it is a relatively low-cost procedure and it does not create any major problems as might be the case with methods using water.

Table 2.11. Summary of Representative Cost and Productivity Data for Reservoir Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Drain	1,000	0.0001	0.0001	--	--
Scrape	656	0.41	0.18	0.23	--
Dredge	163	1.42	0.81	0.61	--
Ion Exchange	495	17.07	0.36	4.60	12.11

A step up from vacuuming, in terms of effectiveness, is a low-pressure water wash. This reduces the committed individual dose by 98/96.25 percent from the inhalation/external pathway and is accomplished for about $0.23 per sq meter. Both vacuuming and low-pressure hosing require very little in the way of equipment. Almost all of the cost of these two operations is for labor.

Using a high-pressure water source raises the effectiveness somewhat. If high-pressure water mains are located in the area being treated, then the necessary equipment will involve only several lengths of fire hose, a nozzle, and a ladder. Hosing is done with two- or three-man crews and most of the cost is still for labor. However, in the event that a pumper truck is necessary to generate the required water pressure, the cost of the procedure rises from about $0.74 to $2.34 per sq meter, and labor's share of the input cost falls sharply.

Table 2.12. Summary of Representative Cost and Productivity Data for Roof Decontamination Operations

Operation	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Material
Vacuum	81	0.23	0.21	0.02	--
Low-Pressure Water	81	0.23	0.22	0.01	--
High-Pressure Water	81	0.74	0.72	0.02	--
Wet Sandblast	19	4.84	3.87	0.97	--
Fixative	81	1.22	0.43	0.56	0.23
Foam	81	1.73	0.86	0.79	0.08
Strippable Coating	81	3.26	0.91	0.58	1.77
Remove and Replace	24	19.08	12.95	0.43	5.70

Sandblasting can be done either wet or dry. Both methods, however, pose serious potential for recontamination of adjacent surfaces. Dry blasting generates airborne dust, while wet blasting can spread the contamination via runoff. However, there is a technique called vacuum blasting in which the dry blast is combined with a vacuum intake which surrounds the blast nozzle. The result is that dust and sand do not escape from the area being blasted. However, the coverage with this apparatus is so slow that this method is likely to be prohibitively expensive.

At $4.30 per sq meter for dry blasting without dust control, and $4.84 per sq meter for wet blasting without water treatment, these operations are sufficiently costly that they are likely to be used only in special situations. Wet blasting is appropriate where water could be allowed to either absorb into the soil or run into storm drains. Working from the top down on a roof with a good slope, it is estimated that this method can achieve a reduction in the committed individual dose from the inhalation/external pathway of 97/93 percent.

A fixative to prevent resuspension can be applied in much the same manner as other materials such as foam or strippable coating. An appropriate choice of fixative in this use might be Compound SP-301. This forms a thin latex coating over the surface. Once cured, it can be removed, but to do so requires use of a solvent. This operation is particularly advantageous when used in conjunction with other operations such as removal and replacement.

Acidic foam can be used on roofs to draw contaminants out of surface cracks and irregularities. This material is applied using the type of spray truck used for commercial lawn and tree spraying. To remove the foam, a long extension to the standard hose intake of a mobile vacuum sweeper is used. The cost of this operation is around $1.73 per sq meter.

Strippable coating is applied to roofs in much the same way as foam, except that a nonaerosol spray is used. Again, a mobile spray truck is the basic piece of equipment. Removal, however, is largely a manual operation, with a worker pulling off pieces of the coating for later pickup. Despite the considerable labor time involved for this operation, about 54 percent of the $3.26 per sq meter cost is for the coating material itself. In addition to achieving an estimated reduction in the committed individual dose from the inhalation/external pathway of 85/80 percent, a strippable coating acts as an effective fixative.

The most effective and the most costly operation for decontaminating roofs is simply to remove and replace them. To assure that the radioactive particles on the roof surface are in fact removed and not scattered over

surrounding surfaces, actual removal should be preceded by coating the roof with road oil to fix the particulates to the roof. Roof removal and replacement are steps for which there is some established experience-based cost data available. Of course, the cost of removal, and especially that of replacement, depend in large part on the type of material used. For five-ply, built-up tar and gravel construction, the total cost is estimated at $18.51 per sq meter. For asphalt strip shingles, the cost is less, and for cedar shingles the cost is more. Removal and replacement is estimated to have nearly total effectiveness.

2.4.3.2 Exterior Walls

Three types of exterior walls are considered here: painted wood, brick and concrete. In addition, exterior glass surfaces are also considered. Painted wood surfaces are characteristic of residential structures, while brick is assumed characteristic of both residential and commercial structures and concrete characteristic of industrial structures. Except for construction-type operations, such as removing and replacing the walls, treatment operations are identical for the three surfaces with respect to costs and rates of coverage. However, decontamination efficiencies for these surfaces are not the same. In general, the greater roughness and porosity of brick and, to a lesser extent, concrete make decontamination methods less effective.

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

Washing and scrubbing results in good removal through the abrasive action of scrubbing. The cost estimates for this operation are based on information supplied by commercial cleaning companies.

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

Vacuuming has the particular advantage of creating no byproduct of contaminated water. In addition, at $0.18 per sq meter, the operation is relatively inexpensive.

Hydroblasting involves shooting an extremely high-pressure water jet at the surface. Equipment is available that cuts into or through the wall, so some care must be taken to select the proper water pressure. This operation

is provided on a contract basis. Some models of this equipment have the added advantage of using very little water. What water is used can be picked up with a wet vacuum.

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

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

Both foam and strippable coating are applied with paint spray equipment. Foam is removed by vacuuming, and the strippable coating is removed by hand. The costs and rates for operations on exterior walls are summarized in Tables 2.13 and 2.14.

Exterior glass surfaces represent a special situation when considered as a surface type. First, as a practical matter, the same decontamination method used on adjacent exterior wall surfaces should be used on the glass, if this can be done without damage. Two characteristics of windows (and sliding glass doors) are noteworthy in this regard: 1) because of the hardness and smoothness of glass surfaces, decontamination efficiencies will generally be higher than for other wall surfaces; and 2) they are more vulnerable to damage, rendering such operations as vacuum blasting or hydroblasting inappropriate.

A second reason why windows may require special consideration is that removal and replacement necessarily affects both interior and exterior surfaces. Thus, the cost-effectiveness of replacement depends on treatment costs for the interior window surface as well as for the exterior surface.

In view of the dependency of the glass decontamination method on that selected for the adjacent wall surface, we apply the following multi-step procedure. The first step is to see if the method selected for use on the adjacent wall can be used effectively on the glass. If it can be used without damaging the windows and its efficiency is adequate, then that method is selected--provided that another method is not required and that the selected method does not contain a restricted operation.

The justification of this approach is that it would likely be too costly not to use the same method on the windows as on the adjacent walls. Otherwise

Table 2.13. Summary of Representative Cost and Productivity Data for Decontamination Operations on Exterior Wood Walls

Operation	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
Water wash	203	0.091	0.086	0.005	--
Wash and scrub	10	1.75	1.15	0.60	--
Fixative	40	0.834	0.555	0.049	0.23
Vacuum	69	0.18	0.16	0.02	--
Hydroblast	11	8.50	3.39	5.11	--
Medium-pressure water	8	2.43	2.18	0.25	--
Remove, replace, paint	7.6	24.35	18.33	0.23	5.79
Remove structure	14.9	10.62	5.76	4.86	--
Foam	40	0.869	0.715	0.071	0.083
Strippable coating	40	2.92	1.09	0.06	1.77

the windows may need to be shielded from the wall decontamination procedure or otherwise avoided. Also, there would be a duplication of set-up costs and effort.

The second step is to ensure that the method used on windows meets the cleanup criterion; this is likely to be the case since almost all of the methods used on walls have a higher removal efficiency when used on windows. Except for removal and replacement, the cost per square meter is assumed to be the same on windows as on the adjacent walls. For example, if the indicated

Table 2.14. Summary of Representative Cost and Productivity Data for Decontamination Operations on Exterior Brick Walls

Operation	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
Water wash	203	0.091	0.086	0.005	--
Wash and scrub	10	1.75	1.15	0.60	--
Fixative	40	0.834	0.555	0.049	0.23
Vacuum	69	0.18	0.16	0.02	--
Medium-pressure water	8	2.43	2.18	0.25	--
Hydroblast	11	8.50	3.39	5.11	--
Scarify	4	22.68	20.85	1.83	--
Remove and replace	1.35	166.01	118.65	5.37	41.99
Remove structure	11.1	22.94	11.89	11.05	--
Foam	40	0.869	0.715	0.071	0.083
Strippable coating	40	2.92	1.09	0.06	1.77