The removal efficiency of any one operation, therefore, depends not only on the effectiveness in removing materials from one or more of the three states, but the fraction of the total contamination in each of the particular states. Unfortunately, the range of uncertainties with respect to the dispersal of the contaminants throughout the reservoir makes it impossible to accurately predict the distribution among the three states. However, based on the presumption of atmospheric transport, it is likely that there would be fewer of the heavier particles which would settle out. We assume that ten percent of the radionuclides will settle to the bottom, 25 percent will remain as suspended solids, and 65 percent will be in solution.

Operations routinely used to treat the water supply may also be effective against radioactive contamination with little or no additional treatment costs. These procedures include flocculation in which suspended solids and some dissolved materials are caused to precipitate out. Aluminum hydroxide is used in municipal water treatment systems as a flocculent. In addition, filtration can remove suspended solids.

Below, we consider several different operations for decontaminating a reservoir.

A.2.1.1 Drain

The simplest operation for decontaminating a reservoir is to release the contaminated water to the downstream watercourse. Whether this operation can be used, however, depends largely on the nature of the watercourse, as discussed above. If the water released is diluted sufficiently with other water sources, or if the expected damage from the contaminated water is low, then draining the reservoir may be the preferred alternative. Another consideration is the availability of alternative water supplies. In many situations, substitute water sources may be less costly than removing the contaminants from the water.

The estimated cost of draining the reservoir does not include the cost of alternate water supplies. There are two components to the cost of draining a reservoir. The first has to do with draining of the reservoir. According to a source at the city of Seattle, Washington Water Department, this cost would be negligible since the procedure simply involves opening the outflow values or turning on a pump or siphon system. A nominal labor charge of $0.0001/m^2 is assumed to account for periodic inspection of the draining procedure.

The second cost component is the damage incurred downstream due to the release of the contaminated water. Under the methodology being used here, these losses would not be included in decontamination costs, but rather should be associated with property value losses.

In addition to removing a large portion of the contamination, draining the reservoir makes it possible to scrape up the contaminated sediment from the lake bottom. Under some circumstances it might be desirable to refill (or partially refill) and drain the reservoir one or more times and then scrape the bottom. The intent would be to use the reservoir to settle out a portion of the suspended contaminants washed down by natural precipitation.

A.2.1.2 Scrape

Scraping could be done following draining of the reservoir. (See Sections A.1.1.5 and A.1.3.3 for discussion of scraping and for the development of cost and rate estimates.) Here we assume that scraping the reservoir bottom would be the same as scraping vacant land.

A.2.1.3 Dredge

Contaminated sediment can be removed from the bottom of the reservoir by dredging. A hydraulic dredge would be more effective than a clamshell or dragline dredge. Means' Building Construction Cost Data 1982 (p. 28) provides information about such an operation. There are two components to the dredging operation. The first is mobilization and demobilization. The second is the dredging itself.

Since reservoirs normally are not dredged, it is unlikely that dredging equipment will be at or near the site. Therefore, the maximum mobilization-demobilization costs are used here. The labor requirements for mobilization include one outside foreman at \$22.25 per hour, two building laborers at \$19.40 per hour each, two medium equipment operators at \$24.95 per hour each, one oiler at \$21.45 per hour, and two heavy-truck drivers at \$19.75 per hour each. The total hourly labor cost comes to \$171.90.

The equipment required includes one 25-ton hydraulic crane at \$50.58 per hour, one front-end loader at \$72.46 per hour, and two heavy dump trucks at \$35.72 per hour each. The total heavy equipment cost is \$194.48.

The listed production rate for the maximum dredging mobilization-demobilization cost implies that a total or ten days or 80 hours would be required for mobilization and demobilization, excluding an allowance for the one-hour-per-shift adjustment. Applying this adjustment, the total labor and equipment mobilization-demobilization cost comes to:

Labor: \$171.90/hr x 80 hr x 8/7 adj = \$15,716

Equipment: \$194.48 x 80 hr x 8/7 adj = \$17,781

The calculation of the costs on a dollars-per-sq-meter basis is done later.

The labor involved in dredging includes one outside foreman at \$22.25 per hour, two building laborers at \$19.50 per hour each, one equipment (crane) operator at \$25.62 per hour, one light equipment operator at \$23.70 per hour, and one oiler at \$21.45 per hour. The total hourly labor cost is \$131.82.

The equipment listed by Means includes a 25-ton crawler crane at $50.74 per hour, a centrifugal water pump at $7.86 per hour, a six-inch suction hose at $1.79 per hour, and 1000 feet of six-inch discharge hose at $34.10 per hour. The hourly equipment cost totals to $94.49.

The maximum cost production rate for dredging is listed as 310 cubic yards per day. Assuming a dredging depth of six inches, the coverage is equal to six sq yards per cubic yard.

There are various ways to add in the mobilization-demobilization costs and to calculate costs per sq meter, but all require some arbitrary assumptions. One approach is to assume the reservoir size. The cost per sq meter and the implied coverage rate can be calculated to allocate the cost of mobilization-demobilization over the time necessary to dredge an area the size of the whole reservoir. The problem with this approach is that basing these calculations on anything other than an exceptionally small reservoir results in an unreasonably long time until job completion. For example, a seven sq mile reservoir would take over 40 years to dredge at one shift per day.

The approach taken here is to assume that enough dredges would be employed so that the job would be completed in about one year. To accomplish this with the one-hour-per-shift adjustment implies that the total coverage would be accomplished in about 7/8 of a year if the adjustment were not required. This area is:

$$310\ \text{yd}^3/\text{day} \times 6\ \text{yd}^2/\text{yd}^3 \times 7/8\ \text{adj} \times 52\ \text{wk} \times 5\ \text{day/wk} = 310\ \text{yd}^3/\text{day}$$

$$\times\ 6\ \text{yd}^2/\text{yd}^3 \times 45.5\ \text{wk} \times 5\ \text{day/wk} = 423{,}150\ \text{yd}^2.$$

Converting to sq meters gives:

$$423{,}150\ \text{yd}^2 \times 0.8361\ \text{m}^2/\text{yd}^2 = 353{,}796\ \text{m}^2.$$

Adding the time for mobilization-demobilization, we obtain

$$(45.5\ \text{wk} \times 40\ \text{hr/wk} + 80\ \text{hr}) \times 8/7\ \text{adj} = 2171\ \text{hr}.$$

Therefore, the overall rate is:

$$423{,}150\ \text{yd}^2 \times 0.8361\ \text{m}^2/\text{yd}^2 \div 2171\ \text{hrs} = 163\ \text{m}^2/\text{hr}.$$

The labor and equipment costs of mobilization-demobilization per sq meter can be calculated by dividing the total costs by the total coverage.

$$\text{Labor: } \frac{\$15,716}{353,796\ m^2} = \$0.04/m^2$$

$$\text{Equipment: } \frac{\$17,781}{353,796\ m^2} = \$0.05/m^2$$

The dredging costs are similarly calculated on the basis of totals. The total labor cost is:

$$\$131.82/hr \times 45.5\ wk \times 40\ hr/wk \times 8/7\ adj = \$274,185$$

The total equipment cost is:

$$\$94.49/hr \times 45.5\ wk \times 40\ hr/wk \times 8/7\ adj = \$196,539$$

The cost on a dollars-per-sq-meter basis are:

$$\text{Labor: } \frac{\$274,185}{353,796\ m^2} = \$0.77/m^2$$

$$\text{Equipment: } \frac{\$196,539}{353,796\ m^2} = \$0.56/m^2$$

Table A.2.1.1 summarizes these results and provides total costs per sq meter.

TABLE A.2.1.1. Summary of Dredging Cost Data

	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment
Mobilization-Demobilization	--	0.09	0.04	0.05
Dredging	--	1.33	0.77	0.56
Total	163	1.42	0.81	0.61

OAGI0001550_00320

A.2.1.4 Ion Exchange

Ion exchange is a process that can remove ionic solubilized contaminants from the water. The procedure involves passing the water through a bed or column of cation exchange resin and one of anion exchange resin. Alternatively, some systems use a mixed bed of ion exchange resins. As water passes through the system, hydrogen ions on the cation exchange resin are exchanged for cations in the water, and hydroxide ions on the anion exchange resin are exchanged for anions in the water. The hydrogen and hydroxide ions react with each other to produce an effluent of pure water.

At some point the resins become saturated with the captured ions and lose their effectiveness. When this happens the resins can be replaced or regenerated by chemical treatment. The regeneration process produces a liquid waste with relatively high levels of (radioactive and/or nonradioactive) ions.

The effectiveness of this systems depends on the degree of contact or exposure of the water to the resins. Longer columns and smaller resin beads increase the removal efficiency, but reduce flow rates. In addition, most resin exchange systems are nonselective as to the ions removed. Therefore, water with a high content of salts will require more frequent resin regeneration.

Ion exchange systems are one of the few ways of removing (some) dissolved contaminants; the procedure is also quite expensive. The high cost of the ion exchange method has resulted in relatively few systems with the high volume capacity that would be necessary for treating reservoir outflow.

Two commercial sources of ion exchange systems were contacted for information. Aquanetics, Inc., in Seattle, Washington is also the local outlet for Culligan Water Service. The representative for Aquanetics estimated that for reservoir water with higher-than-average dissolved minerals, say about 250 ppm, the cost of ion exchange treatment would range from about $0.06 per gal with resin regeneration to $0.30 per gal with single use of the resin. Resins are good for about five use cycles. Further, with resin regeneration there is a production of waste water in the amount of about one gal of waste to every 100 gal of processed water.

Crowley Environmental Services in Seattle, Washington provided more detailed information. According to this source, minimum average cost is achieved with a plant with a 1000 gpm capacity. For greater output rates, additional plants would be built. Such plants are highly automated and use a continuous resin regeneration system. According to one source, the removal efficiency could be as high as 99 percent.

For a 10,000 gpm capacity, a total of $75 to $110 million dollars would be required for plant design and construction. Operation of the plant would require four operators on duty at all times. In addition, there would be supervisory and maintenance personnel. Materials, specifically resins, would cost about $0.01 per gal.

Assuming a plant operating life of five years, equipment costs would be roughly 20 million dollars per year. At 10,000 gpm the yearly output would be 5.256×10^9 gal. The equipment cost would be \$0.0038 per gal.

Assuming a labor cost of \$30 per hour and an average of six employees on duty at all times, the hourly labor cost would be \$180. Since the hourly output is 600,000 gal, the cost for labor would be \$0.0003 per gal.

It is necessary to convert these costs to a cost per m^2 of reservoir area. This can be done by assuming an average reservoir depth of 15 ft. Thus, each sq meter of reservoir area represents a certain volume of water. This volume is equal to 161.46 cu ft. At 7.5 gal/ft^3, there are 1211 gal/m^2 of reservoir area. Therefore, the costs per m^2 are:

$$\text{Labor: } \$0.003/\text{gal} \times 1211\ \text{gal/m}^2 = \$0.36/\text{m}^2$$

$$\text{Equipment: } \$0.0038/\text{gal} \times 1211\ \text{gal/m}^2 = \$4.60/\text{m}^2$$

$$\text{Materials: } \$0.01/\text{gal} \times 1211\ \text{gal/m}^2 = \$12.11/\text{m}^2$$

The total cost per m^2 is \$17.07.

At 10,000 gpm the coverage rate is:

$$10{,}000\ \text{gal/min} \times 60\ \text{min/hr} \div 1211\ \text{gal/m}^2 = 495\ \text{m}^2/\text{hr.}$$

A.3 STRUCTURES

A.3.1 Roofs

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

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

A.3.1.1 Vacuuming

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

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

This source estimates that a 1000 sq foot roof could be vacuumed in 45 minutes. Adding 15 minutes for moving to the next roof gives an average rate of 1000 sq feet per hour. With one hour per every eight-hour shift set aside for equipment and personnel radiation decontamination, the estimated total coverage in one shift is 7000 sq feet. Converting to sq meters per shift-hour, we get an average production rate of 81 sq meters per hour. The average unit cost is:

$$\frac{\$18.95/\text{hr} \times 8\ \text{hr}}{7000\ \text{ft}^2 \times 0.093\ \text{m}^2/\text{ft}^2} = \$0.23/\text{m}^2$$

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

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

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

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

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

A.3.1.2 Low-Pressure Water Flushing

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

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

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

A.3.1.3 High-Pressure Water

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

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

Some data on the productivity of hosing roofs has been compiled from actual experience. The Administrative Services Manager of Spokane Community College in Spokane, Washington, directed the cleanup of the campus following the 1980 eruption of Mount St. Helens. That catastrophic event covered all exterior surfaces with a layer of volcanic ash. Roofs were cleaned by fire-hosing. They found that the average productivity was 7500 sq feet per man-hour. However, this rate was achieved on large, institutional-sized buildings. Not so much time was spent shifting from one roof to another and shifting from one hydrant to another. Further, the data on decontamination efficiency do not indicate the amount of water necessary to achieve the stated removal percentages. In general, one would expect that in terms of actual hosing time, high-pressure hosing would take no longer and might be somewhat faster than low-pressure hosing. On the other hand, moving from one roof to another may take somewhat longer, even with the extra manpower, due to the weight and stiffness of the hose as well as the wider spacing of hydrants.

On the basis of these considerations, we estimate a rate almost identical with that for low-pressure hosing: 40 minutes for a 1000 sq foot roof and 20 minutes to move from roof to roof. The production in an eight-hour shift would be 7000 sq feet after including time for equipment and personnel radiation protection measures. Again, the average coverage per hour would be 81 sq meters.

The costs would include those for labor and for equipment. Here we assume three-man crews, giving a labor cost of $58.35 per hour. In addition, there are the costs for a ladder and hose. The length of hose necessary depends on the spacing of the hydrants. If hydrants are placed every other block, then they will be somewhat more than 600 feet apart. This suggests that hosing crews should have sufficient hose to cover everything in a radius of more than 300 feet. We estimate that 500 feet of 1-1/2-inch hose, ten sections of 50 feet each, should be enough for the average crew. Referring to the costs in Table A.1.5.3.1, we see that the hose sections, with couplings, cost $550 in constant 1982 dollars. With nozzle and other miscellaneous fire equipment, the cost comes to about $600. With the ladder, the total is about $675.

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

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

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

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

A.3.1.4 Sandblasting

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

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

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

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

$$2000\ ft^2 \div 8.67\ hr \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 19\ m^2/hr$$

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

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

The cost shares are approximated in the following way. The cost per shift for sandblasting varies from about $400 to $800 per shift depending on whether it is wet or dry blasting and depending on whether a light or more thorough coverage is achieved. Labor cost for the two workers will be somewhat higher than the assumed base wage rate of $17.45 due to the special equipment operating skills required. If we assume a labor cost of $20 per worker, labor's share of the cost is somewhere in the range of 40 to 80 percent. The latter figure seems more consistent with others derived, so it is taken as representative. Remaining costs are for equipment.

A.3.1.5 Fixative

Like several other operations, application of a fixative involves spraying the surface with some chemical mixture using paint spraying or similar equipment. Fixatives and their characteristics are explained in Section A.1.1.2. Of the fixatives discussed, Compound SP-301 appears to be an appropriate choice for use on roofs.

If it is not necessary to strictly confine the applied fixative to the roof surface, it can be applied with a device such as a hydroseeder. This is a mobile tank truck equipped to spray liquids to areas adjacent to roads. It is typically used by highway departments for seeding areas next to roads and for other liquid treatments of roadside surfaces. According to the Washington State Department of Transportation, a hydroseeder has the capability of covering an acre per hour with the required coating of 0.4 gallons per sq yard.

This works out to a 32 gpm pump rate. A hydroseeder might be used to apply fixative to roofs if lawns are to be coated with fixative and if building sides are to be replaced. The estimated cost of application by this method, excluding the cost of the fixative, is $1.19 per sq meter, the same cost as applying fixative to lawns. The calculations for this cost estimate are explained in Section A.1.9.5.

It is more likely, however, that a carefully confined application of fixative will be required. This could be accomplished using mobile sprayers of the sort described for the application of foam and strippable coating to roofs. Minor modifications probably would be necessary so that a nonaerosol spray could be used, though this should not have any significant impact on the estimated costs of this method of application. Therefore, the estimated cost of $0.99 per sq meter for application is used in this case, as well (see Section A.3.1.6). To this must be added the cost of the fixative which is calculated at $0.23 per sq meter in Section A.1.1.2. This brings the total cost of applying fixative to $1.22 per sq meter. Again, this operation requires two workers and a spray truck with miscellaneous equipment such as ladders, hoses, and so forth.

A.3.1.6 Foam

The basics of foam decontamination technology are described in Section A.1.5.5. In that section, the cost per sq meter for chemicals is calculated as $0.083. To this cost need to be added the costs of application and removal.

Mobile sprayers of the sort used for commercial lawn, shrub, and tree spraying or paint sprayers appear to have the capability to apply decontamination foam. Ac[illegible]ing to commercial lawn spraying services such as A-Z Pest Control in R[illegible]d, Washington, and Roger's Spray and Tree Service in Seattle, Washington, [illegible]rucks have a capacity of around 300 gallons and the ability to deliver an aerosol spray at the rate of 32 gpm.

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

Assuming 45 minutes per 1000 sq foot roof and 15 minutes to move from one roof to the next, the average daily production during seven out of eight hours would be 7000 sq feet. This works out to 81 sq meters per hour. The cost of application per sq meter, including labor is, then:

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

The cost of labor per sq meter is

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

The cost of equipment as calculated similarly is

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

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

$$8777\ m^2/hr \times \$0.0043/m^2 = \$37.74/hr$$

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

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

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

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

To find the total cost of the foam treatment to roofs, we add the costs of the separate parts. This brings the total to $1.54 per sq meter. These data are summarized in Table A.3.1.6.1.

TABLE A.3.1.6.1. Summary of Cost and Productivity Data for Foam Decontamination of Roofs

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

A.3.1.7 Strippable Coating

The essentials of strippable coating as a decontamination method are described in Section A.1.5.6. The cost for using this technique on roofs is calculated much as the costs for foam decontamination are calculated in the previous section.

In Section A.1.5.6, the cost of the chemicals for strippable coating is estimated at $1.77 per sq meter. To this amount must be added the costs of application and removal. Again, a modified mobile landscape spray truck or paint spraying equipment, as is suggested for application of foam to roofs, could be used for applying strippable coating as well. The pump and nozzle apparatus would have to be modified to produce a nonaerosol spray, but even with these modifications a charge of $45 per hour for equipment should be adequate. With two workers the total cost of application would be $80 per hour and $0.99 per sq meter.

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

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

Using the base labor charge, the cost of labor per shift for stripping would be $140. To this we add the cost of incidental equipment such as knife and ladder. One dollar per hour would cover this, so the shift total for incidental capital would be $8 and the shift total for removing the coating would be \$148. Assuming 3.5 roofs, or 3500 sq feet, stripped per shift, the average hourly coverage is 41 sq meters. The unit cost is:

$$\frac{\$148/\text{shift}}{3500\ \text{ft}^2/\text{shift} \times .093\ \text{m}^2/\text{ft}^2} = \$0.45/\text{m}^2$$

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

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

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

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

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

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

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

The foregoing information is compiled in Table A.3.1.7.1. It is clear that chemicals comprise a major part of the overall cost. One implication of this is that crude bulk application techniques, such as hosing the roof with strippable coating from the ground, are probably not cost effective. While there would be savings in per-unit labor costs due to the faster rate of application, such a method would likely result in a significant increase in the overall amount of chemical solution required since a larger portion of it would

TABLE A.3.1.7.1. Summary of Cost and Productivity Data for Decontamination of Roofs Using Strippable Coating

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

miss its target. Also, the inability to control thickness as accurately would probably necessitate a higher average volume of coating solution per unit area to assure that minimum thickness requirements were met.

The various steps comprising this operation are combined such that the rate of each was equal to the most costly. Here the most costly step is application with a rate of 81 sq meters per hour. Removal would require nearly two (81/41 = 1.98) removal crews per application crew. Pickup would require only 81/488 = 0.166 crew per application crew.

A.3.1.8 Removal and Replacement

The most effective technique for removing radioactive contaminants on roofs is, of course, to remove the whole roof and replace the roof surface with a new one. However, removal should be preceded by fixing the contamination to the roof to prevent roof removal activities from inadvertently spreading radioactive particulates on surrounding pavement and lawns (see Section A.3.1.5).

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

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

$$1600\ ft^2/day \div 8\ hr/day \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 16\ m^2/hr$$

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

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

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

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

The adjusted production rate is

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

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

Table A.3.1.8.1 summarizes the results of these calculations and shows the total cost for removal and replacement. As previously, the more costly procedure determines the overall rate. Therefore, 24/16 = 1.5 roof removal crews for every roof replacement crew would be required to maintain the rate of 24 sq meters per hour.

A.3.2 Exterior Wood Walls

Exterior painted wood walls are representative of the exterior surface of the large part of residential structures as well as many commercial buildings.

TABLE A.3.1.8.1. Summary of Roof Removal and Replacement Cost Data

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

A.3.2.1 Water Wash

This operation involves hosing the surface with water. The essentials of such a water wash operation are described in the discussions of similar operations in Sections A.1.5.2 and A.3.1.2. In this case no special equipment, such as pumps or special hoses to raise the water pressure or special nozzles, are required. Walls would be hosed using water from existing mains and plumbing. The labor required would be one common laborer whose hourly billing cost is estimated at \$17.45 based on labor costs from Means publications. One dollar per hour should be adequate to cover equipment costs.

The cost per unit area depends on the coverage rate. We estimate a basic rate of 100 sq feet in two minutes, but in addition, about 10 minutes per hour would be necessary for moving to new locations and attaching the hose. This implies a rate of 2500 sq feet per hour. Converting to sq meters and adjusting for one hour per shift for personnel and equipment decontamination, we get:

$$2500\ ft^2/hr \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 203\ m^2/hr$$

Input costs on a dollars-per-sq-meter basis are found by division, as follows.

$$\text{Labor:}\quad \frac{\$17.45/hr}{203\ m^2/hr} = \$0.086/m^2$$

$$\text{Equipment:}\quad \frac{\$1.00/hr}{203\ m^2/hr} = \$0.005/m^2$$

The total cost is the sum of these two figures, \$0.091 per sq meter.

A.3.2.2 Wash and Scrub

Two sources provided information on costs and rates for washing and scrubbing walls. Northwest Janitorial Systems of Seattle, Washington, advised that they charge between $0.15 and $0.20 per sq foot for wall cleaning. This cost applies to both interior and exterior walls. This source further indicated that the total hourly cost is about $15.00. These figures imply an adjusted production rate of about six to eight sq meters per hour. We use a rate of six sq meters per hour here. Assuming that labor comprises 80 percent of the costs, or $12.00 per hour, the labor cost comes to $1.72 per sq meter. The equipment cost is $0.43 per sq meter, and the total comes to $2.15 per sq meter.

American Building Maintenance of Seattle, Washington, indicated both a higher rate (200 sq feet per hour) and a higher hourly cost ($18.50 per hour). The adjusted coverage rate comes to 16 sq meters per hour with a total cost of $1.14 per sq meter. The labor cost is $0.69 per sq meter, and equipment accounts for $0.45 per sq meter.

Table A.3.2.2.1 summarizes this information and shows the representative cost and rate figures.

TABLE A.3.2.2.1. Summary of Data for Wash and Scrub of Walls

Source	Rate (m^2/hr)	Cost (1982 $/$m^2$)		
		Total	Labor	Equipment
Northwest Janitorial Systems	6	2.15	1.72	0.43
American Building Maintenance	16	1.14	0.69	0.45
Representative	10	1.75	1.15	0.60

A.3.2.3 Fixative

A general discussion of fixatives is provided in Section A.1.1.2. For application to walls, Compound SP-301, with a cost of $0.23 per sq meter, appears to be the best choice. Since this material can be applied in the same manner and with the same equipment as spray painting, the application cost is estimated on the basis of this activity.

The basic data source for spraying is Means' Building Construction Cost Data 1982 (pp. 231, 236). The daily coverage rate is given as 4000 sq feet. This converts to

$$4000\ ft^2/day \div 8\ hr/day \times 0.0929\ m^2/ft^2 \times 7/8\ adj = 40\ m^2/hr$$

The costs are listed as $22.55 per hour for an ordinary painter and $2.00 per hour for the spray equipment. Dividing by the hourly coverage rate gives $0.555 per sq meter for labor and $0.049 per sq meter for equipment. Adding the cost of the fixative brings the total cost per sq meter to $0.834.

A.3.2.4 Vacuum

Vacuuming as a decontamination technique is described elsewhere in this Appendix (see Sections A.1.5.1 and A.3.1.1). The primary source of data regarding the vacuuming of walls is American Building Maintenance of Seattle, Washington. This source advises that the hourly cost for vacuuming exterior walls would be $18.50 per hour with about $11.14 for labor. This figure implies a cost of $7.36 per hour for equipment. However, this figure includes extra equipment such as a van or a pickup truck, which is not necessary for this operation. The equipment cost for the vacuum and associated equipment is estimated at $1.50 per hour.

The hourly coverage rate is between 800 and 900 sq feet. This converts to an adjusted 69 sq meters per hour. Dividing the hourly cost figures by the hourly coverage rate yields costs per sq meter: $0.16 for labor, $0.02 for equipment. The total is $0.18 per sq meter.

A.3.2.5 Hydroblast

Hydroblasting uses a high-pressure water jet to scour surfaces. Power Master, Inc. of Seattle, Washington, utilizes two types of hydroblasting equipment for contract hydroblasting work. The type of equipment used depends on the nature of the job and the surface. One type puts out 30 gallons per minute at a maximum of 10,000 to 20,000 pounds per sq inch. If the spray lance is kept moving, this will do minimal damage to the surface. However, there is a safety problem with this equipment. The considerable recoil on the lance makes it hard to hold, and the water jet could cut through a person.

The other unit is an ultra-high-pressure system, generating a water jet up to 55,000 pounds per sq inch. However, since only 1.9 gallons per minute is expelled, there is little or no recoil, making the lance much easier to control. The lance can be operated with a rotating head that keeps the jet moving around in a six-inch diameter circle. This reduces the risk of boring a hole through the surface being blasted and permits cleaning with a six-inch wide swath.

Since either equipment can be operated at lower pressures appropriate for surfaces such as wood, the costs for the second system are used here as representative for hydroblasting. The basic charge is $96 per hour, including the operator. However, more than one lance can be operated with each of the 475-horsepower truck-mounted V-12 pumps. There is an additional charge of $44 per hour per lance, up to a maximum of five. The calculations here are based on a cost of $70 per hour per lance, which is consistent with two lances per truck.