The rate of coverage, adjusting for one hour per shift for radiation control measures, is

$$1057\ m^2/\text{house} \div 6\ \text{hr/house} \times 7/8\ \text{adj} = 154\ m^2/\text{hr}\ .$$

A.6.1.5 Manual Survey of Exterior Surfaces

Surveying of exterior building surfaces using hand-held instruments can be performed in a manner similar to that just described for interior building surfaces. Exterior surfaces include lawns, wooded areas, and paved surfaces. As compared with interior surfaces, the surveying need not be as intensive for these areas. If the surveying intensity is reduced by half, then the cost per sq meter is halved to $0.19 per sq meter, and the coverage rate doubles to 308 sq meters per hour.

Wooded areas are an exception to this. The restricted access of wooded terrain is expected to approximately cancel the gains made possible by the reduced sampling intensity for other exterior surfaces. Therefore, the assumed cost per sq meter is $0.38, and the assumed rate is 154 sq meters per hour.

A.6.1.6 Placement of TLDs

Five-chip TLDs (thermo-luminescent dosimeters) are useful for long-term monitoring of residual radioactivity. Their initial placement for monitoring radioactivity of exterior surfaces is described in this section. In the next section the periodic retrieval of exposed TLDs, analysis and replacement are presented.

TLDs are widely used for environmental and personal exposure monitoring. Several sources were able to supply information based on actual experience with these devices. They include U.S. Testing, Inc., the Environmental Evaluations Section of Pacific Northwest Laboratory, and the Washington Public Power Supply System. In addition to the considerable amount of experience with TLDs, those devices have the advantages of being small, reliable, and inexpensive to purchase and operate.

For extended monitoring of exterior surfaces, one TLD per 10 sq miles is assumed to be adequate. Initial placement would require a technician to drive to the site and to attach a TLD holder to a convenient surface or, if necessary, to a fence post driven into the ground. After putting the dosimeter in the holder and documenting the location, the technician would move to the next location.

Costs for this operation are estimated as follows. The labor cost for technicians is assumed at $25 per hour. Equipment costs have three components: the vehicle, tools and miscellaneous equipment, and the TLD with its holder. According to Means (1982), a two-wheel drive pickup truck costs $412.50 per month plus $4.42 per hour for operation. Assuming 21 8-hr shifts

per month, this comes to an hourly cost of $6.87. To this we add an estimated $1.00 per hour for tools and miscellaneous equipment, such as fence posts.

The cost of the TLDs and holders in dollars per hour depends on the rate at which they are installed. To this end, the installation time cycle is decomposed into travel time, time for locating and installing the device, and time for documenting the precise location of the TLD. For travel between locations, an average vehicle speed of 25 miles per hour and an average driving distance of 15 miles is assumed. This gives an average travel time of 36 minutes.

For installing the TLD, 30 minutes is assumed. In addition, 10 minutes for documentation is allotted. With travel, total time estimated for dosimeter placement is about 1.25 hours. In 7 working hours per 8-hour shift, 5.6 dosimeters would be installed; over the total eight hours, this is equivalent to 0.7 dosimeters per hour. With a cost per TLD of $17.50, this comes to $12.25 per hour. This price for the TLD comes from U.S. Testing and includes analysis and reporting. Also, there is the cost of the TLD holder which a representative of the Washington Public Power Supply System estimated at $4.75. At 0.7 holders per hour, the hourly cost is $3.33. The total hourly equipment cost for truck, tools, TLD and holder comes to $23.45.

The last major cost category for this operation is administration. As with other surveying and monitoring operations, this is estimated at 46 percent of labor cost, or $11.50 per hour in the present case.

To convert these costs to a dollars-per-sq-meter basis, it is necessary to calculate the area covered per shift hour. As mentioned, TLDs would be placed at a rate of 0.7 dosimeters per hour. With the TLDs placed at a density of one per ten sq miles, the net coverage rate is 7 sq miles per hour, or 1.81×10^7 sq meters per hour. Dividing this figure into the hourly costs gives $\$1.37 \times 10^{-6}$ per sq meter for labor, $\$1.29 \times 10^{-6}$ per sq meter for equipment, and $\$6.34 \times 10^{-7}$ per sq meter for administration. The total cost comes to $\$3.29 \times 10^{-6}$ per sq meter.

A.6.1.7 Replacement of TLDs

Periodically it will be necessary to remove the TLDs for reading and analysis. At the same time, a replacement TLD would be installed. This operation involves driving to the various locations, exchanging TLDs, completing any necessary documentation, and moving to the next site. Collected TLDs would be forwarded to the appropriate facility for analysis and reporting.

Again, the estimated labor cost is $25/hr. Since the worker would not have to carry tools, TLD holders, or posts for mounting the holders, a smaller vehicle than that used for initial placement could be used. The estimated hourly vehicle cost is $6.00.

The dosimeters comprise the sample analysis costs. With 36 minutes travel time between TLD locations and ten minutes for replacement and documentation, about 0.75 hours per dosimeter are required. This is equal to 9.33 TLDs

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replaced during the seven production hours of an eight-hour shift. In an average shift-hour 9.33 : 8 = 1.17 TLDs would be replaced. At $17.50 per dosimeter (including analysis), the cost per hour is $20.48.

Again, based on 46 percent of labor costs, administration costs would be $11.50 per hour.

With one dosimeter every ten sq miles and an adjusted replacement rate of 1.17 TLDs per hour, the coverage rate is equal to 11.7 sq miles per hour. This is equivalent to 3.03 x 10^7 sq meters per hour. Dividing the hourly costs by the adjusted hourly coverage rate gives the following adjusted costs per sq meter: labor - $8.25 x 10^{-7}; equipment - $1.98 x 10^{-7}; sample analysis - $6.76 x 10^{-7}; and administration - $3.80 x 10^{-7}. The total cost per sq meter is therefore $2.08 x 10^{-6}.

A.6.1.8 Air Sampler Operations

Additional monitoring can be achieved through the use of permanent air samplers. According to PNL's Environmental Evaluations, these would be placed initially so that the coverage would be one machine for every 30 sq miles. This is an average density, and cost calculations are made on this basis. Actual spacing would have samplers closer together in areas of greater population density and further apart in rural areas. Also, samplers would be positioned around the perimeter of interdicted areas to monitor the transport of radionuclides from those areas.

Air samplers would be set up shortly before decontamination operations begin. Due to the expected short half-lives of most of the constituent radionuclides, the number of samplers could be reduced periodically. After six months, the number of operating samplers could be reduced by half; thereafter, the number of remaining samplers would be decreased gradually over the next 30 years, when a minimum number of samplers would be reached. This minimum number would continue to be operated for another 10 years. The reason for this extended monitoring is to insure against inadvertent exposure which might occur, for example, during the demolition of a building. Some radionuclides could have remained unremoved and undetected beneath the building only to become resuspended with the demolition activity.

As an example of the changing number of samplers, we assumed an initial placement of 100 units. Six months later the number of machines in operation would be reduced to 50. From then on, the number would be diminished at a constant rate to 10 in year 30. These 10 machines would be operated until year 40. As machines are removed, it may be advantageous from time to time to reposition some of the remaining air samplers.

A.6.1.8.1 Placement of Permanent Air Samplers. Permanent air sampler stations do not involve extensive equipment or construction. A permanent air sampler can be set up by a single technician in about an hour.

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It is assumed that the initial number of air samplers would be purchased rather than rented or leased. As the number of samplers in operation is reduced, the retired samplers would be used for replacement of damaged units and a source of replacement parts.

The labor cost for the required technician is assumed at \$25/hr. The time to drive from one air sampler location to the next is estimated at one hour. Installation time is assumed to require another hour. Allowing for testing, adjustments, initial loading of materials onto the truck, and so forth, it is estimated that one technician can set up three stations in the seven production hours of an eight-hour shift.

The equipment used to set up the air sampler includes a pickup truck, simple tools, and a calibrator. The development of the cost estimates for the truck (\$6.87 per hour) and the tools (\$1.00 per hour) is discussed in Section A.6.1.6. The calibrator, which is used to adjust the air sampler for proper operation, costs about \$300. Since the calibrator is not a part of the air sampler, it can be used in the installation of several air samplers. An hourly equipment charge of \$1.00 is assumed to cover the calibrator cost.

The air sampling station consists of a small shelter that costs about \$200, an air movement system that costs about \$1500, a TLD that costs \$17.50, and other miscellaneous parts that cost about \$200. The total cost of the air sampler equipment is therefore about \$2000. Assuming three stations per shift, the cost per hour is

$$\$2000/\text{sampler} \times 3\ \text{samplers/shift} \div 8\ \text{hr/shift} = \$750\ \text{per hour.}$$

Adding to this the cost of the truck, tools and calibrator, the total hourly equipment cost comes to \$758.87. Administration costs estimated at 46 percent of labor add another \$11.50 per hour.

Assuming 30 sq miles per sampler and three sampler installations per shift, the adjusted coverage rate is 90 sq miles per shift. This is equal to 11.25 sq miles per hour which, in turn, is equal to 2.91×10^{7} sq meters per hour. Dividing this into the hourly labor, equipment and administration costs gives respective costs per sq meter of $\$8.58 \times 10^{-7}$, $\$2.60 \times 10^{-5}$, and $\$3.95 \times 10^{-7}$. The total cost per sq meter comes to $\$2.73 \times 10^{-5}$.

A.6.1.8.2 Operation and Maintenance of Air Samplers. There are two different operation and maintenance cost schedules for air samplers. The first pertains to the six months following the contamination event; the second relates to the period beyond six months. The primary reason for the different schedules is that in the first 6 months the number of air samplers in the field is constant, whereas from then on until year 30 the number is gradually declining. The two operation and maintenance cost schedules are discussed below.

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Initial Operation and Maintenance of Air Samplers. Once in place, it would be necessary for someone to retrieve for analysis the filters from the air samplers and to install new filters. Further, the TLDs placed with the sampling equipment must also be replaced periodically. Finally, these regular visits to the sampling stations would be combined with a maintenance program.

The retrieval of air filters for analysis is assumed to occur once every two weeks, with quarterly replacement of TLDs. There would also be a separate schedule for maintenance as described below. The data for all three of these functions have been calculated in terms of the biweekly schedule for air filter retrieval.

Each time the filter is replaced about an hour of driving time would be required. Another 0.25 hours would be necessary for changing the filter, checking the machine's operation, and completing the necessary documentation. With a total of 1.25 hours required per machine, 5.6 machines could have their filters exchanged during the 7 production hours of an 8-hour shift. The net hours per machine is therefore,

$$8 \text{ hr} \div 5.6 \text{ machines} = 1.43 \text{ hr/machine}$$

At $25/hr for a technician, this comes to $35.75 per machine.

Equipment costs would consist of a pickup truck at $6.87 per hour and negligible costs for filters, forms, and other small items. With 1.43 hours per machine, the equipment costs per machine come to $9.82. Sample analysis of each filter would cost about $31. Since TLDs need to be exchanged for analysis on a quarterly basis, the biweekly cost is computed by dividing the cost of the TLD analysis by 6.5. At $17.50 per TLD analysis, the TLD cost per air sampler filter change is

$$\$17.50 \div 6.5 = \$2.69 \text{ per filter}$$

The total sample analysis cost per sample station is, therefore, $33.69. With 5.6 stations per shift, the hourly cost is

$$\$33.69/\text{station} \times 5.6 \text{ stations} \div 8 \text{ hr} = \$23.58/\text{hr}.$$

At 46 percent of labor costs, administration adds another $11.50 per hour, or $16.45 per sample station.

Equipment maintenance would include a program of regular replacement of the air movement mechanism. The program would involve rotation of machines

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every six months for servicing. Machines removed from service at six months would be used as a source of reserve equipment and also as a source of spare parts.

Maintenance expenses include approximately 3 hours of repair to 10 percent of the machines per year. In addition, there is the labor at $25/hr required for removing and replacing equipment for servicing. Recalibration of samplers plus recalibration of the calibrators would also be required. These annual labor costs associated with maintenance are estimated at $75 per station, or about $3.00 per station per air filter retrieval. The administration cost associated with labor for maintenance comes to $1.38.

Table A.6.1.4 summarizes the costs per sample station and provides totals for the various cost categories.

TABLE A.6.1.4. Operation and Maintenance Costs per Sample Station ($1982)

	Total	Labor	Equipment	Sample Analysis	Administration
Operation	$ 98.71	$35.75	$9.82	$36.69	$16.45
Maintenance	4.38	3.00	--	--	1.38
Total	$103.09	$38.75	$9.82	$36.69	$17.83

Source: Pacific Northwest Laboratory.

The coverage rate is based on the rate of sample collection. With 5.6 stations per 8-hour shift, there are 0.7 stations per hour. Since there is one air sampler for every 30 sq miles, the coverage rate is equal to 0.7 x 30 = 21 sq miles per hour. This is equivalent to 5.44×1^{-7} sq meters per hour. Multiplying the costs per sample station by 0.7 sample stations per hour and dividing by the hourly coverage rate yields costs in terms of dollars per sq meter. The costs per sq meter for labor, equipment, sample analysis and administration are $\$4.99 \times 10^{-7}$, $\$1.26 \times 10^{-7}$, $\$4.72 \times 10^{-7}$ and $\$2.29 \times 10^{-7}$, respectively. Summing these gives the total cost per sq meter of $\$1.32 \times 10^{-6}$.

<u>Extended Operation and Maintenance.</u> Beyond the time when half the air samplers are removed, the gradual reduction in the number of remaining samplers implies a reduction in the maintenance and operation costs per sq meter. Rather than recalculate a cost each time the number of machines changes, a cost formula is developed here that can be applied to all periods. Unfortunately, not all of these costs can be expressed as a simple function of the number of samplers because total costs do not decline proportionately with the decline in sampler density. This is because costs associated with travel between samplers will increase on a per-sampler basis as samplers are removed. The cost formula, therefore, combines two types of costs to develop a consistent estimate of costs per sq meter. The first type, associated with travel, is assumed

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to remain constant in relation to the whole area being monitored. The second type remains constant per sampler and consequently diminishes on a dollar-per-sq-meter basis as the number of samplers declines.

The original estimate of travel time between sites was one hour. Here it is assumed that after removing half the machines, travel time between samplers would double to two hours. These time estimates combined with the PNL Environmental Evaluations assumption of an initial 100 machines give a total travel time estimate of 100 hours over the assumed 3000 sq miles being monitored. Adjusting and converting to a dollars-per-sq-meter basis, and assuming labor at \$25/hr, we have

$$\$25/\text{hr} \times 100 \text{ hr} \times 8/7 \text{ adj} \div 7.77 \times 10^{9} \text{ m}^{2} = \$3.68 \times 10^{-7}/\text{m}^{2}.$$

Similarly calculated, equipment consisting of a pickup truck would cost

$$\$6.87/\text{hr} \times 100 \text{ hr} \times 8/7 \text{ adj} \div 7.77 \times 10^{9} \text{ m}^{2} = \$1.01 \times 10^{-7}/\text{m}^{2}.$$

Administration, at 46 percent of labor, adds another \$11.50 per hour. The cost per sq meter is

$$\$11.50/\text{hr} \times 100 \text{ hr} \times 8/7 \text{ adj} \div 7.77 \times 10^{9} \text{ m}^{2} = \$1.69 \times 10^{-7}/\text{m}^{2}.$$

The total travel cost comes to $\$6.38 \times 10^{-7}$ per sq meter.

For each machine, 0.25 hours is estimated as necessary for changing the filter, checking the machine's operation and completing the necessary documentation. With the usual 8/7 time adjustment, the labor cost, assuming \$25/hr for a technician, would be

$$\$25/\text{hr} \times 0.25 \text{ hr} \times 8/7 \text{ adj} = \$7.14;$$

the equipment cost for the pickup truck would be

$$\$6.87/\text{hr} \times 0.25 \text{ hr} \times 8/7 \text{ adj} = \$1.96;$$

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and the cost for administration would be

$$\$11.50/hr \times 0.25\ hr \times 8/7\ adj = \$3.29.$$

As discussed earlier, sample costs per machine for analyzing the filter would be about $31. In addition, TLD analysis would cost an average of $2.69 per biweekly visit to the sampler station. The total sample cost per machine is, then, $33.69.

Costs per sampler can be converted to a dollars-per-sq-meter basis using the PNL Environmental Evaluations machine reduction schedule. An equation giving the number of machines (M) for monitoring 3000 sq miles as a function of time (T) is

$$M = 50.678 - 1.3559\ T \qquad 0.5 < T < 30$$

Here T equals 0.5 when, half a year after original placement, the number of machines is reduced from 100 to 50.

Maintenance costs per machine, excluding travel, must also be added. Table A.6.1.5 shows maintenance costs per machine. Since there is no additional travel time required for maintenance, no travel time is included in these figures. Total operation and maintenance costs per machine, excluding travel costs, are summarized in Table A.6.1.5.

TABLE A.6.1.5. Operation and Maintenance Costs per Air Sample Station Excluding Travel Costs ($1982)

	Total	Labor	Equipment	Sample Analysis	Administration
Operation	$46.08	$ 7.14	$1.96	$33.69	$3.29
Maintenance	4.38	3.00	--	--	1.38
Total	$50.46	$10.14	$1.96	$33.69	$4.67

Source: Pacific Northwest Laboratory.

To convert these costs to a dollars-per-sq-meter basis, the cost per sampler is multiplied by the number of samplers, M, and divided by the total area being monitored. These nontravel costs are then added to the travel costs to give the total costs per sq meter.

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For labor the nontravel cost per sampler is \$10.14. The number of samplers is M, and the total area being monitored is 7.77×10^9 m^2. Specifically, the nontravel labor costs in dollars per sq meter are

$$10.14 \times (50.678 - 1.356\ T) \div 7.77 \times 10^9\ m^2 = 6.61 \times 10^{-8} - 1.77 \times 10^{-9}\ T.$$

Adding the labor travel costs we obtain the formula for total labor costs per sq meter.

$$6.61 \times 10^{-8} - 1.77\ T \times 10^{-9} + 3.68 \times 10^{-7} = 4.34 \times 10^{-7} - 1.77 \times 10^{-9}\ T.$$

Similarly calculated, the formula for equipment costs is

$$1.14 \times 10^{-7} - 3.42 \times 10^{-10}\ T \text{ (dollars per sq meter).}$$

The sample cost per sq meter is

$$2.20 \times 10^{-7} - 5.88 \times 10^{-9}\ T \text{ (dollars per sq meter).}$$

The administration cost per sq meter is

$$1.90 \times 10^{-7} - 5.74 \times 10^{-7}\ T \text{ (dollars per sq meter).}$$

The total cost per sq meter comes to

$$9.67 \times 10^{-7} - 8.81 \times 10^{-9}\ T \text{ (dollars per sq meter).}$$

A.6.1.8.3 Removal of Air samplers. The following subsections discuss the initial removal of half the samplers and the subsequent gradual removal and repositioning of the remaining samplers.

Initial Removal of Samplers. Six months after initial placement, half the air samplers could be removed. The costs for this operation follow the same approach used in the previous section. Again, one technician at \$25/hr would be required. Because half the samplers are to be removed, the travel time between samplers to be removed is estimated at twice the time to drive to

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installation locations. Equipment required would include one pickup truck at $6.87 per hour and miscellaneous tools at $1.00 per hour. Administration at 46 percent of labor would cost $11.50 per hour.

It is estimated that disassembly of the station and packing it into the pickup truck would take about half an hour. Including driving time, this comes to 2.5 hours per removed sampler. In the 7 productive hours per shift, 2.8 stations could be removed.

The area to which these costs apply is the total area, including areas monitored by remaining stations. This is because the operation represents a thinning of station density over the total area. since the original average station density was one for every 30 sq miles, and half the stations were removed, each station removed is associated with an area of 60 sq miles. The average coverage per shift hour is

2.8 stations/shift x 60 sq mi/station ÷ 8 hr/shift = 21 sq mi/hr

This is equal to 5.44×10^7 sq meters per hour.

In terms of dollars per sq meter, labor, equipment and administration costs are $\$4.60 \times 10^{-7}$, $\$1.45 \times 10^{-7}$ and $\$2.11 \times 10^{-7}$, respectively. The total cost is $\$8.16 \times 10^{-7}$ per sq meter.

Gradual Removal of Samplers. After reducing the number of operating samplers by half six months after initial placement, there would be an extended period of gradual reduction in the number of remaining samplers. Based on the number of machines and their previously assumed density, it is estimated that about 1.36 samplers would be removed per year. To keep the cost of this operation at a minimum, it would be combined with regular operation and maintenance so that no additional travel time would be required.

Labor costs would be $25/hr for a single technician. Equipment costs include costs for a pickup truck and miscellaneous tools. Although the pickup truck is not moving during the time of disassembly, it is necessary nonetheless to account for its cost at $6.87 per hour. In addition, miscellaneous tools would be required at $1.00 per hour. Administration would cost 46 percent of labor costs, or $11.50 per hour.

Removal of a single station is estimated above to req[illegible] half an hour. Thus, to remove 1.36 stations it would take

0.5 hr/station x 1.36 stations/yr = 0.68 hr/yr.

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Adjusting this for radiation control measures yields

$$0.68 \text{ hr/yr} \times 8/7 \text{ adj} = 0.78 \text{ hr/yr}.$$

This station reduction operation applies to the total area being monitored, which is 3000 sq miles. The 0.7 hours required for annual sampler removal give a coverage rate of

$$3000 \text{ sq mi} \div 0.78 \text{ hr} = 3846 \text{ sq mi/hr}.$$

This is equal to 9.96×10^{9} sq meters per hour. Dividing this figure into the hourly costs gives costs on a dollars-per-sq-meter basis. They are $\$2.51 \times 10^{-9}$, $\$7.90 \times 10^{-10}$, and $\$1.15 \times 10^{-9}$, for labor, equipment and administration, respectively. The total cost per sq meter is $\$4.45 \times 10^{-9}$.

A.6.1.9 Soil and Crop Sampling

Radiological contamination of agricultural fields and orchards is of special concern because of the threat of ingestion of contaminated foods. As outlined by PNL's Environmental Evaluations Section, the procedure would involve a technician driving to a farm and collecting four soil samples and four crop samples. These samples would then be sent to a laboratory for analysis.

To estimate a coverage rate and to establish a reasonable sampling density, it is helpful to obtain an estimate of average farm size. According to the Statistical Abstract of the United States (1984) the average U.S. farm size in 1983 was 437 acres. Based on this figure, we estimate about 15 minutes to drive from one farm to the next. Sources at PNL estimated about 45 minutes for the collection of soil samples and another 20 minutes for plant samples per farm. These time estimates total to 1.33 hours per farm. In seven hours, 5.25 farms would be sampled. This is equal to 9.28×10^{6} sq meters in an eight-hour shift, or 1.16×10^{6} sq meters per shift-hour.

The hourly cost of a technician for collecting samples is assumed at $25. Dividing the hourly cost by the hourly coverage, we get a cost per sq meter of $\$2.15 \times 10^{-5}$ for labor.

The major equipment cost is for a pickup truck. As described previously in Section A.6.1.6, the hourly cost for the pickup truck is estimated at $6.87. In addition, miscellaneous tools and sample collection materials would have an estimated cost of $1.00 per hour. The total hourly equipment cost is, then, $7.87. This converts to $\$6.78 \times 10^{-6}$ per sq meter for equipment.

Sample analysis is the major cost component. Each soil sample would be given a gamma scan and a strontium analysis. All four plant samples would be given a gamma scan and one of the four samples would be tested for strontium.

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The cost of a gamma scan for a soil or a plant sample is about \$56, and the cost of a strontium test for a soil or a plant sample is about \$155. Therefore the total cost of sample analysis for the four soil samples is \$844, while that for the four plant samples is \$379. The total sample analysis cost comes to \$1223. The hourly sample analysis cost is

$$\$1223/\text{farm} \times 5.25 \text{ farms/shift} \div 8 \text{ hr/shift} = \$803/\text{hr}$$

Dividing this by the hourly coverage yields \$6.92 x 10^{-4} per sq meter for sample analysis.

The final cost category is for administration. Estimated at 46 percent of labor, this comes to \$11.50 per hour, or \$9.91 x 10^{-6} per sq meter. Summing the unit costs for labor, equipment, sample analysis and administration gives a total cost of \$7.30 x 10^{-4} per sq meter.

A.6.1.10 The Frequency and Extent of Surveying and Monitoring Operations

To be able to compute the total surveying and monitoring costs associated with a serious reactor accident, it is necessary to know, in addition to these costs, the frequency with which the surveys have to be taken and the territory that must be surveyed and monitored. We now turn to addressing these issues. Aerial surveys are assumed to include all of the area that produces a reading of 0.1 mrad/hour or greater. The first aerial survey should be conducted as soon after the accident as practicable, and three additional aerial surveys should follow at 6-month intervals. Then, beginning in the 4th year following the accident, aerial surveys should be conducted every two years through the tenth year. Because of radioactive decay, weathering, and decontamination operations, the area that must be covered on each successive aerial survey will be less than for the preceding survey.

The mobile air sampling survey should be conducted right after the accident, and should cover the same area encompassed by the aerial survey. As already noted, ground, water and vegetation samples should be taken as needed at the same time as the air samples are taken. No repeat surveys of this kind are required.

During decontamination, there should be a monitoring and bioassay program for decontamination workers. However, the requirements for such a program have not been developed for this report.

Following decontamination, interior and exterior surfaces need to be surveyed. The mobile gamma scanner appears to be well-suited for external surfaces, while manual survey techniques are to be applied to interior surfaces. For exterior surfaces that are inaccessible to the mobile gamma scanner, it will be necessary to use manual survey techniques. However, these are considerably more costly. Only a single application of these survey methods will be required, provided that the decontamination process has successfully reduced the contamination levels.

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Agricultural land will require a more rigorous surveying and monitoring program. Core samples must be taken of the soil; the recommended frequency is one sample per farm, four times in the first year, and once a year after that for four years. In addition, where livestock are present, tissue samples will be required on each farm, four times in the first year and annually thereafter.

For continuous monitoring of exterior surfaces, permanent air monitoring stations need to be established. Each air station is equipped with an air sampler and, in addition, a TLD. It is estimated that 100 of these would be adequate to monitor a 3,000 sq mile area, but they would be concentrated in areas with denser populations. The filters on the air sampler are changed every two weeks, and the TLDs are replaced quarterly. In addition to the 100 TLDs installed at the air monitoring stations, an additional 200 TLDs should be installed elsewhere throughout the affected area, especially in populated areas.

Table A.6.1.6 summarizes the cost and rate information on surveying and monitoring techniques presented in Sections A.6.1.1 through A.6.1.9. The assumed schedule for surveying and monitoring operations is summarized in Table A.6.1.7 below.

TABLE A.6.1.6. Summary Information of Surveying and Monitoring Techniques

Surface	Operation	Rate m^2/hr	Total $/$m^2$	Labor $/$m^2$	Equip. $/$m^2$	Sample Analysis	Administration
All exterior horizontal surfaces	Aerial survey	3.24×10^8	1.61×10^{-5}	9.26×10^{-7}	1.44×10^{-5}	--	4.26×10^{-7}
All exterior surfaces	Mobile air and soil sampling	7.55×10^7	3.23×10^{-6}	6.62×10^{-7}	8.19×10^{-8}	2.19×10^{-6}	3.05×10^{-7}
Ground surfaces	Supplemental water and plant sampling	7.55×10^7	3.26×10^{-6}	--	--	3.26×10^{-6}	--
Bldg. walls, ext. horiz. surfaces, except roofs	Mobile gamma scanning	2.58×10^5	7.28×10^{-4}	2.91×10^{-4}	3.03×10^{-4}	--	1.34×10^{-4}
Bldg. surfaces	Manual survey	154	.4602	.1622	.0130	.2104	.0746
Exterior surfaces	Manual survey	308	.2301	.0811	.0065	.1052	.0373

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TABLE A.6.1.6. contd

Surface	Operation	Rate m^2/hr	Total $\$/m^2$	Labor $\$/m^2$	Equip. $\$/m^2$	Sample Analysis	Administration
Wooded areas	Manual survey	154	.3602	.1622	.0130	.2104	.0746
Exterior surfaces	Placement of TLDs	1.81×10^7	3.29×10^{-6}	1.37×10^{-6}	1.29×10^{-6}	--	6.34×10^{-7}
Exterior surfaces	Replacement of TLDs	3.03×10^7	2.08×10^{-6}	8.25×10^{-7}	1.98×10^{-7}	6.76×10^{-7}	3.80×10^{-7}
Exterior surfaces	Set up permanent air samplers	2.91×10^7	2.73×10^{-5}	8.58×10^{-7}	2.60×10^{-5}	--	3.95×10^{-7}
Exterior surfaces	O&M of permanent air samplers[a]	5.44×10^7	1.32×10^{-6}	4.99×10^{-7}	1.26×10^{-7}	4.72×10^{-7}	2.29×10^{-7}
Exterior surfaces	Initial removal of air samplers	5.44×10^7	8.16×10^{-7}	4.60×10^{-7}	1.45×10^{-7}	--	2.11×10^{-7}
Exterior surfaces	Extended removal of air samplers	9.96×10^9	4.45×10^{-9}	2.51×10^{-9}	7.90×10^{-10}	--	2.11×10^{-9}
Agricultural fields and orchards	Soil and crop sampling	1.16×10^6	7.30×10^{-4}	2.15×10^{-5}	6.78×10^{-6}	6.92×10^{-4}	9.99×10^{-6}

(a) Values are for initial operation and maintenance only. Extended operation and maintenance costs must be computed via formula in Section A.6.1.8.2.

A.6.2 Hauling

Hauling is not specific to any particular surface; rather it is an activty which is associated with other operations that generate contaminated material to be removed from the decontamination site to some dump site. Alternatively, some operations, notably those involving covering land areas with uncontaminated soil, require hauling to the decontamination site. Also, it is possible that hauling materials away from the area being decontaminated could be coordinated with hauling materials to the site.

There are two principal variables affecting the cost per sq meter of hauling. One is the distance of the haul. The other is the volume of material

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TABLE A.6.1.7. Schedule of Surveying and Monitoring Activities

Procedure	Frequency in Year Following Release 0	1	2	3	4	5	6	7	8	9	10	D[a]	PD[b]
Aerial Survey	1	2	1	-	1	-	1	-	1	-	1	-	-
Mobile air and Soil Sampling	1	-	-	-	-	-	-	-	-	-	-	-	-
Supplemental Water and Plant Sampling	1	-	-	-	-	-	-	-	-	-	-	-	-
Mobile Gamma Scanning	-	-	-	-	-	-	-	-	-	-	-	1	-
Survey of Building Interiors	-	-	-	-	-	-	-	-	-	-	-	1	-
Survey of Exterior Surfaces	-	-	-	-	-	-	-	-	-	-	-	1	-
Survey of Wooded Areas	-	-	-	-	-	-	-	-	-	-	-	1	-
Placement of TLDs	-	-	-	-	-	-	-	-	-	-	-	1	-
Replacement of TLDs	-	-	-	-	-	-	-	-	-	-	-	4	4
Setup of Permanent Air Samplers	-	-	-	-	-	-	-	-	-	-	-	1	-
Service Permanent Air Samplers													
Initial Service	-	-	-	-	-	-	-	-	-	-	-	13	-
Extended Service	-	-	-	-	-	-	-	-	-	-	-	13	26
Removal of Permanent Air Samplers													
Initial Removal	-	-	-	-	-	-	-	-	-	-	-	-	1
Extended Removal	-	-	-	-	-	-	-	-	-	-	-	-	1
Soil and Crop Sampling	-	-	-	-	-	-	-	-	-	-	-	4	1

(a) Activities performed in the year property is decontaminated.
(b) Activities performed in the years following decontamination. See text for details.

Source: Pacific Northwest Laboratory.

per sq meter to be hauled. This latter variable depends on the particular operation and surface. These two important cost variables are discussed below.

The primary source of information for estimating the relationship between cost and distance is Means' Building Construction Cost Data 1982. There are different options for hauling crews. For example, debris boxes could be used rather than dump trucks. Dump trucks, however, seem to offer the greatest flexibility and would be significantly more costly than debris boxes only when truck loading is very slow.

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The inputs for hauling are one heavy-truck driver at $19.75 per hour and one 20-cubic-yard dump truck at $45.84 per hour. The total hourly cost is $65.59. According to this source, loading a dump truck with a front-end loader takes 0.3 hours. For off-road work and short hauls, Means assumes an average vehicle speed of ten miles per hour. For longer distances, we assume higher average speeds.

Table A.6.2.1 shows the calculation of the costs of hauling per cubic meter. Most of the table is self explanatory. The third column, showing the time required for the haul, includes the time for loading and dumping. The cost per load is calculated by multiplying the hourly cost by the time. The cost per cubic meter is calculated by dividing the cost per load by 15.292 cubic meters per load. The rate is calculated by dividing 15.292 cubic meters per load by the time. Note that labor comprises 30% of the costs.

TABLE A.6.2.1. Estimated Hauling Costs and Rates by Mileage

Round Trip Distance (miles)	Average Vehicle Speed (mph)	Time (hrs)	Cost (1982 $) Per Load	Per m^3	Rate (m^3/hr)
1	10	0.4	26.24	1.72	38.23
2	10	0.5	32.80	2.14	30.6
3	10	0.6	39.35	2.57	25.5
4	10	0.7	45.91	3.00	21.8
5	10	0.8	52.47	3.43	19.1
10	15	0.9	63.43	4.15	15.8
20	25	1.1	72.15	4.72	13.9
30	30	1.3	85.27	5.58	11.8
50	40	1.55	101.66	6.65	9.9
100	40	2.80	183.65	12.00	5.5

Given the cost per cubic meter for hauling, it is next necessary to estimate the volume of material per sq meter for each operation requiring hauling in order to get a hauling cost per sq meter. Table A.6.2.2 shows the estimated volume of material per sq meter for each operation requiring hauling.

A.6.3 Waste Burial

This section presents the development of cost and rate estimates for burial of solid debris and waste generated by other decontamination operations. The materials to be disposed of include such items as removed walls, floors, roofs, pavement, soil, and strippable coating. These materials are expected to fall into Class A low level nuclear waste as defined in 10 CFR 61. Such materials require simple burial. It is not necessary to line or cover the burial pit with a waterproof material, nor would it be necessary to put materials in special barrels, drums, or tanks. However, site selection is likely to take into account the possibility of radionuclide migration through the soil. For this reason, burial in impervious clay soil or above a rock strata

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TABLE A.6.2.2. Estimated Volume of Material per Square Meter to be Hauled

Surface	Operation	Volume (m^3/m^2)
Agricultural Fields	Scrape	0.15
	Clear	0.10
	Cover	0.15
Orchards	Hand scrape	0.12
	Scrape	0.15
	Radical prune	0.05
	Cover - Trees removed	0.15
	Cover - Trees not removed	0.12
	Remove and replace	0.10
Vacant Land	Scrape	0.15
	Clear	0.10
	Cover	0.15
Wooded Land	Grub and scrape	0.20
	Clear	0.22
	Hand scrape	0.15
	Cover - cleared land	0.15
	Cover - land not cleared	0.15
Asphalt Roads	Plane	0.083
	Resurface	0.083
	Remove and replace	0.33
Other Asphalt Surfaces	Plane	0.083
	Resurface	0.083
	Remove and replace	0.33
Concrete Roads	Plane	0.083
	Resurface	0.083
	Remove and replace	0.33
Other Concrete Surfaces	Plane	0.083
	Resurface	0.083
	Remove and replace	0.33
Lawns	Close mow	0.04
	Remove and replace	0.11
Reservoirs	Scrape	0.15
	Dredge	0.20
Ion Exchange		0.05
Roofs	Remove and replace	0.20

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TABLE A.6.2.2. contd

Surface	Operation	Volume (m^3/m^2)
Exterior Wood Walls	Remove and replace	0.15
Exterior Brick Walls	Remove and replace	0.30
	Remove structure	1.00
Exterior Concrete Walls	Scarify	0.025
	Remove and replace	0.30
	Remove structure	1.00
Exterior Glass	Remove and replace	0.10
Interior Wood/Plaster Walls	Remove and replace	0.20
Interior Concrete Walls	Scarify	0.025
	Remove and replace	0.30
Interior Glass	Remove and replace	0.10
Carpeted Floors	Remove and replace	0.17
Linoleum Floors	Remove and replace	0.05
Wood Floors	Remove and replace	0.20
Concrete Floors	Scarify	0.03
	Resurface	0.03
Hard-Surface Furnishings	Remove and replace	18.00
Soft-Surface Furnishings	Reupholster	1.00
	Remove and replace	12.00
Electronic Equipment	Remove and replace	1.00
Paper Products	Machine copy	1.00
Auto Interiors	Reupholster	0.05
Auto Tires	Remove and replace	0.33

might be selected. Burial at one of the existing waste disposal sites is another possibility. However, the following cost estimates do not include special fees beyond the cost of burial paid to licensed waste disposal companies.

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The procedure for waste disposal involves, first, the excavation of a pit. The soil removed from the pit would be transported to a nearby location. Second, the pit would be filled with waste that was originally removed from the pit. Most costs in this operation are based on volume rather than sq measure. As a result, these cost estimates apply whether one big pit is used or several smaller pits. Next, some of the excavated soil would be hauled back to the filled waste pit to be applied as a two-foot thick cover over the waste materials.

Remaining soil is removed in the process of pit excavation could be used as a source of soil for the decontamination operation of covering areas with uncontaminated soil (see Section A.1.1.9). There are two possible restrictions to using this soil in this way. The first is that the soil at the pit site may be of poor quality for farming or similar use. This is more than a remote possibility because the disposal site might be chosen in a location of heavy clay or rock because of the low permeability of these soil types. The second reason that the burial site may be a source of poor soil is that the location selected for the burial pit is likely to have few valuable alternative uses such as agriculture.

The primary source for information on excavation is Means (1982). This information is presented in Section A.5.9, dealing with covering areas with clean soil as a decontamination operation. Converting the data on excavation from sq meters to cubic meters, we get:

$$\text{Rate: } 812 \text{ m}^2/\text{hr} \times 6 \text{ in deep} \times 0.054 \text{ m/in} = 124 \text{ m}^3/\text{hr}$$

$$\text{Total: } \$0.166/\text{m}^2 \times \frac{812 \text{ m}^2}{124 \text{ m}^3} = \$1.09/\text{m}^3$$

$$\text{Equipment: } \$0.123/\text{m}^2 \times \frac{812 \text{ m}^2}{124\text{m}^3} = \$0.81/\text{m}^3$$

These costs are based on average soil type. Means specifies a cost increase of 60 percent for heavy soil or stiff clay. Such an adjustment should be matched with an adjustment to the production rate. Specifically, the rate should be multiplied by 1/1.60 = 0.625. The resulting rate would be 78 cubic meters per hour. The total cost per cubic meter would be \$1.74, of which labor would account for \$0.45 and equipment \$1.29. We take the costs for normal soil as representative.

The excavated soil needs to be transported to a spot near the burial pit. This would be accomplished with dump trucks. The cost of this hauling depends not only on the cost of operating the trucks and their capacity, but also on

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the expansion of the excavated soil. Means (p. 60) lists a 30 percent swell factor for common earth, 33 percent for hard clay, and 50 percent for well-blasted rock. Using the swell factor for common earth, the excavated volume of 124 cubic meters per hour requires a hauling capacity of

$$124\ m^3/hr \times 1.30 = 161\ m^3/hr$$

With a truck capacity of 20 cubic yards, loading time per dump truck is

$$\frac{20\ yd^3 \times 0.764\ m^3/yd^3}{162\ m^3/hr} = 0.094\ hr = 5.7\ min$$

Referring to Means (p. 59), the remainder of the hauling cycle can be estimated:

Load truck	6 min
Haul	9 min
Dump	2 min
Return	7 min
Position truck	1 min
Total	25 min

At 25 minutes per load, a single truck can haul

$$15.3\ m^3/load \times \frac{60\ min/hr}{25\ min/ld} \times 7/8\ adj = 32\ m^3/hr$$

Note that this rate is in terms of expanded soil. To keep up with one front-end loader,

$$162\ m^3/hr \div 32\ m^3/hr = 5.1$$

dump trucks are required.

The hourly cost of the dump truck driver is $19.75, and the hourly cost for the truck is $35.72. To calculate the cost per "bank cubic meters," rather than loose or expanded cubic meters, it is necessary to convert the hourly rate to pre-expansion dimensions:

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$$32\ m^3/hr \div 1.3 \text{ swell factor} = 25\ m^3/hr$$

The costs are:

$$\text{Labor: } \frac{\$19.75/hr}{25\ m^3/hr} = \$0.79/m^3$$

$$\text{Equipment: } \frac{\$35.72/hr}{44.1\ m^3/hr} = \$1.43/m^3$$

$$\text{Total: } \$0.79 + \$1.43 = \$2.22/m^3$$

If the burial pit is large or if there are several smaller pits, dumping of waste material can proceed while pit excavation is in progress. Means (p. 32) suggests that a building laborer at \$19.40 per hour act as a spotter at the dump site to direct dumping. We estimate one spotter for every 30 trucks per hour. At 15.3 cubic meters per truck, the cost of the spotter is

$$\frac{\$19.40/hr}{30 \text{ trucks/hr} \times 15.3\ m^3/\text{truck}} \times 8/7 \text{ adj} = \$0.05/m^3$$

This includes the adjustment for one hour per shift spent on personnel and equipment decontamination. The rate, in terms of pit volume, is

$$30 \text{ trucks/hr} \times 15.3\ m^3/\text{truck} \times 7/8 \text{ adj} = 402\ m^3/hr$$

Grading and compaction of dumped contaminated material will not only better utilize space within the burial pit, but is necessary to permit dump trucks to be able to drive over dumped debris to add another layer. Means (p. 31) lists the costs for fine grading and compaction. However, the type of grading of concern here need only be rough. Therefore, where Means specifies three passes with the grader and roller, we require only one. For calculation purposes, the rate given by Means is tripled. However, because this rate is given as 1600 sq feet per day, rather than in a volume measure, the first step is to convert the rate from sq to cubic units. To do this, we assume the material is dumped approximately 0.25 meters deep. Thus, for each sq meter

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(yard) graded and compacted, 0.25 cubic meters (yards) are graded and compacted. On this basis, Means' rate becomes

$$1600\ yd^2/day \div 8\ hr/day \times 3\ pass\ adj \times 0.25\ yd^3/yd^2 \times 0.765\ m^3/yd^3$$

$$\times\ 7/8\ adj = 100\ m^3/hr$$

Two medium-equipment operators, at $24.95 per hour each, are required for this work. The total hourly labor cost is $49.90. The 30,000-pound self-propelled grader has an hourly cost of $51.34, and the hourly cost for the ten-ton roller is $20.51. The total equipment cost comes to $71.85. Dividing these hourly costs by the hourly production gives the costs in terms of cubic meters:

$$\text{Labor:}\quad \frac{\$49.90/hr}{100\ m^3/hr} = \$0.50/m^3$$

$$\text{Equipment:}\quad \frac{\$71.85/hr}{100\ m^3/hr} = \$0.72/m^3$$

$$\text{Total:}\quad \$0.50/m^3 + \$0.72/m^3 = \$1.22/m^3$$

Next, the cost of hauling cover soil back to the burial pit from temporary storage must be added. This cost is estimated in the same way as the cost of hauling the soil to the storage site except that, since the soil has already been excavated, we disregard swell factors. Therefore, the costs per cubic meter of cover soil are

$$\text{Labor:}\quad \frac{\$19.75/hr}{32\ m^3/hr} = \$0.62/m^3\ \text{cover}$$

$$\text{Equipment:}\quad \frac{\$35.72/hr}{32\ m^3/hr} = \$1.12/m^3\ \text{cover}$$

$$\text{Total:}\quad \$0.62/m^3 + \$1.12/m^3 = \$1.74/m^3\ \text{cover}$$

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The costs of covering the pit, per cubic meter, are therefore:

$$\text{Labor: } \frac{\$0.42/m^2}{9.1\ m^3/m^2} = \$0.05/m^3$$

$$\text{Equipment: } \frac{\$1.06/m^2}{9.1\ m^3/m^2} = \$0.12/m^3$$

$$\text{Total: } \$0.05/m^3 + \$0.12/m^3 = \$0.17/m^3$$

The rate in terms of cubic meters is

$$137\ m^2/hr \times 9.1\ m^3/m^2 = 1247\ m^3/hr$$

Tables A.6.3.1 and A.6.3.2 summarize the foregoing information. Table A.6.3.1 presents the cost and rate data and Table A.6.3.2 presents the factor input data. Because most of the steps would not be accomplished simultaneously, but sequentially, the overall rate shown should be understood as the basis for scaling the various procedures. Thus, for each separate procedure the scale factors are

Excavation	25/124	= 0.20
Haul	25/25	= 1.00
Spotter	25/402	= 0.06
Grading and Compaction	25/100	= 0.25
Haul	25/480	= 0.53
Cover	25/1247	= 0.02

TABLE A.6.3.1. Summary of Waste Burial Data

Procedure	Rate (m^3 waste/hr)	Cost (1982 $/$m^3$ Waste) Total	Labor	Equipment
Excavation	124	1.09	0.28	0.81
Haul	25	2.22	0.79	1.43
Spotter	402	0.05	0.05	--
Grading and Compaction	100	1.22	0.50	0.72
Haul	480	0.11	0.04	0.07
Cover	1247	0.17	0.05	0.12
Total	25	4.86	1.71	3.15

Source: Pacific Northwest Laboratory

TABLE A.6.3.2. Factor Input Requirements for Waste Burial

Type of Input	Man/Equipment hr/m^3 Waste
Driver, Heavy Truck	1.05
Medium Equipment Operator	.72
Building Laborer	.06
Front-End Loader	.20
Bull Dozer	.02
Ten-Ton Roller	.25
Grader	.25
Dump Truck	1.25

Source: Pacific Northwest Laboratory

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A.6.4 The Distribution of Contaminated Automobiles

The number of automobiles that need to be decontaminated depends on 1) the number of autos per household, 2) whether an evacuation takes place prior to contamination of the area, 3) whether the accident occurs on a weekday or during the weekend, and 4) the time of day of the accident.

To estimate the number of noncommercial automobiles requiring decontamination, we first estimate the number of such vehicles in the area prior to the reactor accident. This is estimated as the number of households in the contaminated area multiplied by the national average number of vehicles per household. Next, we estimate the percent of vehicles used for evacuation, since evacuated vehicles are assumed not to be contaminated.

Information in the Statistical Abstract of the United States 1984 is used as follows to derive an estimate of the national average number of vehicles per household. The number of miles driven by one-vehicle households in 1980 and the number driven by households with two or more vehicles in 1980 is 239.7 and 854.5 billion miles respectively (Statistical Abstract of the United States 1984, Table 1080, p. 622). Adding these two figures gives a total of 1,094.2 billion miles.

The average miles per vehicle per month is about 720 miles (Statistical Abstract of the United States 1984, Table 1080, p. 622). Multiplying this figure by twelve gives an average of 8,640 miles per year per vehicle. The total number of vehicles in households is found by dividing the total number of miles by the average number of miles per vehicle:

(1094.2 bil mi)/(8640 mi/vehicle) = 126.64 million vehicles in households

Dividing this figure by the number of households (Statistical Abstract of the United States 1984, Table 60, p. 47) gives the number of vehicles per household:

(126.64 mil vehicles)/(80.776 mil households) = 1.57 vehicles/household

It should be pointed out that there are significant regional differences in the average number of vehicles per household. Rural areas tend to have more vehicles per household and urban areas with high population densities have fewer.

The most useful sources of information for estimating the percent of household vehicles which would be evacuated are individuals and organizations that study actual disasters, assist in disaster management, or are associated with disaster insurance. Disasters with which these sources have the most experience include hurricanes and floods.

According to several sources, the percent of vehicles used in an evacuation depends on a number of factors. One is the time of day at which the warning is received. If received outside of regular working hours, then families are more likely to be together at home. Since families usually prefer to evacuate as a single unit, they would use a single vehicle for the

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