

Benefit-Cost Evaluation of Using Different Specification Tank Cars to Reduce the Risk of Transporting Environmentally Sensitive Chemicals

CHRISTOPHER P. L. BARKAN, THEODORE S. GLICKMAN, AND AVIVA E. HARVEY

In response to public concerns about the environment, regulatory requirements for cleaning up spills of certain chemicals have become more stringent and cleanup costs have increased dramatically. Hence, due consideration must be given to environmental sensitivity as an element of transportation risk. Among the environmentally sensitive chemicals of most concern to the railroad industry are 10 halogenated hydrocarbons that are shipped in general-purpose tank cars. The cost of cleaning up spills of these chemicals in 1980 through 1989 exceeded \$50 million. This represented more than half of the major environmental cleanup costs resulting from railroad transportation incidents in this period, although shipments of these chemicals accounted for less than 1 percent of the total carload volume of hazardous materials. Investing in more secure tank cars would increase the capital and operating costs but would reduce the risk of these spills. Under current packaging practices, the average liability is estimated to be \$788 per carload in 1990 dollars, and this liability will double in 1992 as a result of more stringent hazardous waste disposal regulations. Use of more secure 105A300W or 105A500W tank cars would reduce the 1990 liability to \$375 or \$129 per carload, respectively. The analytical approach developed in this paper quantifies the benefits and costs of transporting these chemicals in such tank cars. The results indicate that the reduced liability resulting from the use of type 105 tank cars more than offsets the increased capital and operating costs and therefore would be a cost-effective means of reducing the risk.

Industry has a long history of fostering the development of safe equipment and operating practices for the rail transportation of hazardous materials. Over the years, the materials of most concern have been those that pose acute hazards to health and safety, such as poisons, flammables, and explosives. More recently, however, knowledge about environmental degradation has led to increased concern about the impact of releases of chemicals that are hazardous to the environment.

The results of research conducted to identify the highest-priority environmentally sensitive chemicals and evaluate the net economic benefit of replacing the tank cars currently used to transport these chemicals with others that are less likely to release their contents are described in this paper. In general, the direct expenses of environmental cleanup are borne by

the carriers, whereas the cars are paid for by the chemical shippers. However, cleanup expenses that are unnecessarily high increase the overall cost of rail transportation and thereby affect shippers as well as carriers. Furthermore, liability may in some cases be shared with the shipper. It is in the interest of shippers, carriers, chemical customers, and the public that the type of tank car used to transport these chemicals be commensurate with their environmental hazard.

IDENTIFICATION OF ENVIRONMENTALLY SENSITIVE CHEMICALS

The process of identifying the environmentally sensitive chemicals of most concern began by evaluating 83 chemicals currently being shipped by rail and authorized by the U.S. Department of Transportation (DOT) for shipment in general purpose tank cars. These chemicals were evaluated for their relative potential to contaminate soil and groundwater in the event of a large, uncontrolled release. This evaluation was conducted by means of a three-stage hazard assessment of each of these chemicals: first, physicochemical models were used to estimate soil and groundwater dispersion; second, environmental engineering models were used to estimate the difficulty of cleanup based on each chemical's properties and the regulatory requirements for its cleanup; third, the results of these models were supplemented by empirical evidence gathered from the railroads. The results of this analysis indicated that 15 halogenated hydrocarbons were among the chemicals posing the highest environmental cleanup hazard. Ten of these chemicals were considered to be the ones posing the greatest risk of a costly environmental cleanup because of current packaging practices (Table 1). Although authorized for shipment in general-purpose tank cars, the other five halogenated hydrocarbons (allyl chloride, dichloropropane, 1,2-dichloropropene, epichlorohydrin, and ethyl chloride) are primarily transported in DOT-specification 105 or 112 tank cars, which exceed the minimum required by regulations and thus pose a lower risk.

BACKGROUND ON HALOGENATED HYDROCARBONS

Halogenated hydrocarbons have become the focus of intense regulatory scrutiny in recent years because they are widely

C. P. L. Barkan and A. E. Harvey, Research and Test Department, Association of American Railroads, 50 F Street, N.W., Washington, D.C. 20001. T. S. Glickman, Center for Risk Management, Resources for the Future, 1616 P Street, N.W., Washington, D.C. 20036.

TABLE 1 NUMBER OF CARLOADS OF HALOGENATED HYDROCARBONS

Chemical	1987	1988	1989
Carbon tetrachloride	1,647	1,154	1,029
Chlorobenzene	648	624	952
Chloroform	1,155	1,041	1,250
Dichlorobenzene	73	96	55
Ethylene dibromide	3	4	2
Ethylene dichloride	2,314	2,163	3,462
Methyl chloroform	292	914	1,133
Methylene chloride	227	664	883
Perchloroethylene (PERC)	487	842	964
Trichloroethylene (TCE)	271	227	153
PERC/TCE Mixture	51	28	27
Total Reported Carloads	7,168	7,752	9,910
Estimated Actual Carloads (based upon an 84% reporting rate)	8,533	9,228	11,798

used chemicals that can have negative environmental impacts and create chronic health problems. They were among the first hazardous substances generally banned from land disposal by the Environmental Protection Agency (EPA) in 1986 under the Resource Conservation and Recovery Act (RCRA) amendments. They pose a significant challenge in remediation because they are all denser than water and tend to quickly permeate deep into aquifers and stubbornly resist removal. Moreover, the standards for cleanup of contaminated soil and water are stringent because these chemicals are all suspected carcinogens.

The most familiar halogenated hydrocarbons are chlorinated solvents such as trichloroethylene, methyl chloroform, methylene chloride, and perchloroethylene (1). Trichloroethylene (TCE), perchloroethylene (PERC), and methyl chloroform, also known as 1,1,1-trichloroethane (TCA) are the most frequently detected volatile organic compounds contaminating groundwater in the United States (2). TCE has been a widely used degreasing agent for many years. It is classified as a probable human carcinogen and is listed as a hazardous air pollutant and is the chemical most often detected at Superfund sites (3). TCA has widespread application in metal cleaning for decontaminating and degreasing parts, and in electronics for cleaning circuit boards and semiconductors. Methylene chloride (METH) has diverse uses in paint removers, aerosols and chemical processing. PERC, also known as tetrachloroethylene, is used extensively by the dry cleaning industry and as a vapor degreaser for cleaning electrical equipment.

Table 1 presents the number of carloads of the 10 halogenated hydrocarbons reported for 1987, 1988, and 1989 to the TRAIN II data base, which is the record of rail freight movements maintained by the Association of American Railroads (AAR). The total transportation volume of these chemicals has been increasing in recent years, up to an estimated level of about 12,000 carloads in 1989. On a chemical-by-chemical basis, the trend has been downward or stable in some cases and upward in others. Certain ones are being phased out of production over time (e.g., carbon tetrachloride, which

is used as a precursor in freon production), while others continue to be produced and transported at increasing levels [e.g., ethylene dichloride, which is used extensively for polyvinyl chloride (PVC) production]. In some cases, even though domestic demand is declining due to environmental concerns, transportation volume is rising because of export demand.

In 1989 an estimated 1.2 million tank car loads of hazardous materials were shipped in the United States and Canada. The 10 halogenated hydrocarbons accounted for less than 1 percent of this volume. Despite this low percentage, they accounted for approximately 60 percent of the cost of major environmental cleanups (i.e., those costing more than \$250,000) from transportation-related spills reported by the railroads in 1980 through 1989, including four of the five most costly ones (Figure 1).

APPROACHES TO RISK REDUCTION

Risk reduction can be achieved by preventing spills from happening or by reducing their impact when they do happen, or both. Spill impacts are reduced by the effectiveness of the remedial response, which for these chemicals is constrained by such factors as ease of access to the spill location, local geology, proximity of remediation equipment and personnel, and spills of other chemicals that may pose a more immediate concern (acute hazards to human life or property). By contrast, the number of spills can be reduced by two approaches: accident prevention and improved resistance to tank car damage.

The first approach, accident prevention, has been a high priority for the railroad industry in recent years. The railroad accident rate has declined substantially over the past decade (4). The graph in Figure 2 shows that the annual rate of train accidents dropped by more than 60 percent in the period 1980 through 1989, to a level of about 5 accidents per million train-miles in 1989 (5). This reduction can be attributed to investment in physical plant improvements, as well as increased equipment and plant maintenance activities, expanded em-

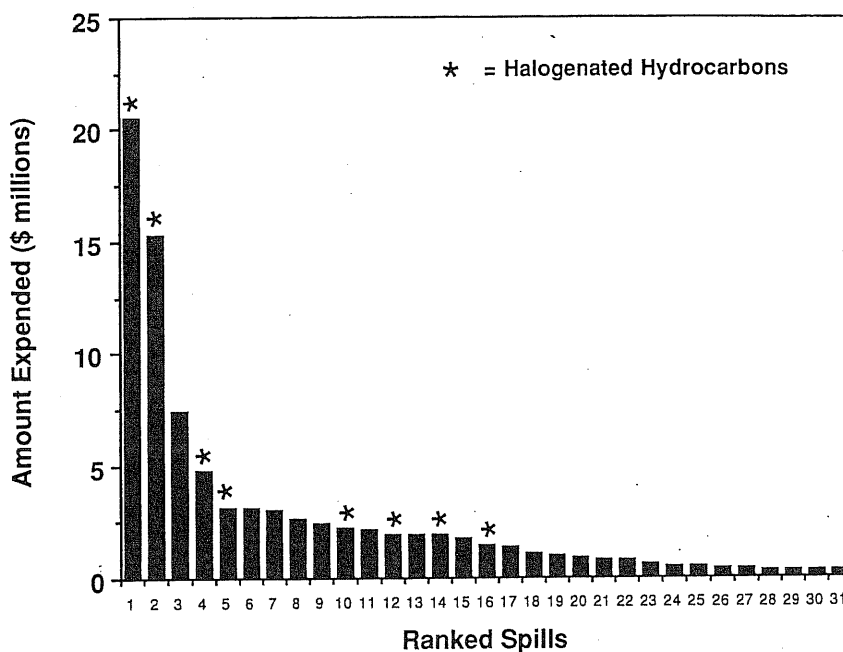


FIGURE 1 Costs of major environmental cleanups from transportation-related spills on railroads, 1980-1989.

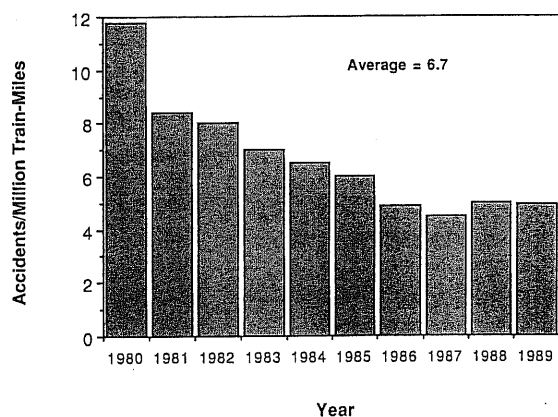


FIGURE 2 Trend in annual accident rate.

ployee training programs and elimination of many low density lines.

The other approach to spill reduction is to use tank cars that are more resistant to damage. The most notable example in recent years is the modification of DOT specification 112/114 tank cars used principally in liquified petroleum gas (LPG) and ammonia service. These cars received head shields, thermal protection, and shelf couplers. Since these changes have been in place there has been a substantial reduction in the frequency of releases from these cars (6). General-purpose 111 tank cars have also undergone improvements over the past decade. Since 1978 all 111s in hazardous materials service have received shelf couplers and (where applicable) bottom outlet protection.

Resistance to damage varies among different types of tank cars. DOT-specification 111 tank cars are generally more likely to suffer a release in an accident than are various pressure

tank cars such as DOT-specification 105 tank cars (7). Most of the cars currently used to transport the halogenated hydrocarbons discussed in this paper are general-purpose, non-insulated tank cars built to DOT specification 111A100W1. These cars have carbon steel tanks and usually come equipped with bottom outlets for convenience in unloading. General-purpose 111 tank cars differ from 105A500W tank cars in several respects related to damage resistance. Most significant are the differences between the thickness and grade of steel used in the tank shell and head. A general-purpose 111 tank car has a $\frac{7}{16}$ -in. head and shell, whereas a 17,000 gallon 105A500W typically has a head and shell greater than $\frac{3}{4}$ -in. thick constructed of higher tensile strength steel, as well as a $\frac{1}{8}$ -in. steel jacket encasing the insulation. As a result, these 105 tank cars have a relatively low likelihood of suffering a puncture in an accident (8).

The other major difference is in the top and bottom discontinuities (fittings) and the accompanying protection. By specification, 105 tank cars have no bottom fittings, whereas general-purpose 111 cars usually have a bottom fitting that extends below the tank. All new tank cars with bottom fittings ordered since the beginning of 1978 have been required to have bottom discontinuity protection, and most older cars in hazardous materials service have been retrofitted under a program developed and administered by the AAR Tank Car Committee. All of the top fittings on a 105 tank car are consolidated and encased in a $\frac{3}{4}$ -in. protective housing, while a general-purpose 111 car may have four or more separate top discontinuities, which are usually not protected [see Figure 3, from General American Transportation Corporation (9)]. Top and bottom discontinuities are both vulnerable to damage in accidents, but the lack of any bottom fittings on the 105 and the protective housing encasing the top fittings contribute to the greater release resistance of these cars.

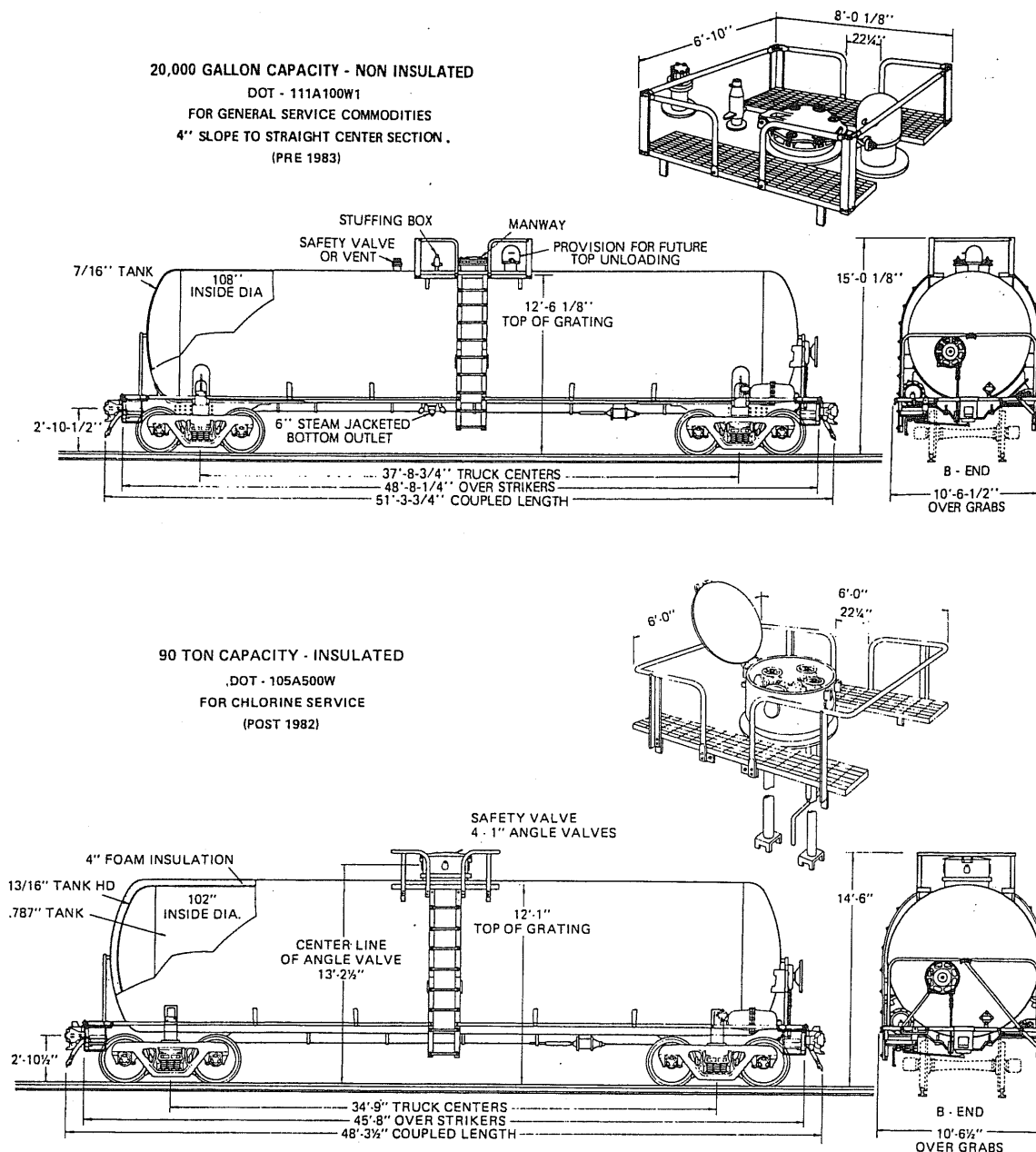


FIGURE 3 DOT specification 111A100W1 (top) and 105A500W (bottom) tank cars.

FORMULA FOR BENEFIT-COST CALCULATIONS

We developed an analytical approach to determine whether the cost of replacing the 111s with the stronger, but heavier and more expensive, 105A500W tank cars would be offset by the benefit of the avoided environmental cleanup expense. The benefit was calculated from data on the cost of cleaning up spills of these chemicals, combined with data on the differences in tank car release probability developed by the Railroad Tank Car Safety Research and Test Project, a cooperative effort of the Railway Progress Institute (RPI) and the AAR. The costs of replacing 111s with 105s are the additional operating expense due to the heavier weight of the 105 tank cars and the net capital expenses associated with putting them

in service and retrofitting the terminals for top unloading. We used a net present value (*NPV*) approach because of the relatively long period of time over which the benefits and costs would accrue.

The *NPV* of replacing the 111s with 105s equals the sum of the benefits of car replacement minus the associated costs, calculated over the years during which the benefits and costs are expected to accrue and discounted to constant (year 0) dollars. The equation used for this calculation is:

$$NPV = \left\{ \sum_{n=1}^N \left[b \prod_{j=1}^n (1 + r_j) - c_i \right] (1 + i)^{-n} \right\} - (c_a + c_m)$$

where

- N = expected lifetime of a tank car (30 years);
 b = average annual benefit of replacing the 111s with 105s, that is, the expected annual reduction in total cleanup costs from transportation spills;
 r_j = real rate of increase in cleanup costs in year j ;
 c_t = average annual incremental cost of transportation if the 111s are replaced with 105s, that is, the increase in the total variable cost of moving the tank cars;
 i = annual discount rate, that is, the annual rate of increase in the real cost of capital;
 c_a = net investment required to acquire the 105s, that is, the cost of the new cars minus the lost value of the cars replaced; and
 c_m = investment required to modify the terminals to accommodate the 105s, that is, to retrofit the terminals for top unloading.

Several assumptions were made to simplify the calculations. First, it was assumed that all of the cars are replaced at the outset, which means that the benefits and the costs of car replacement are realized throughout the 30-year period. Second, it was assumed that the total volume of the 10 halogenated hydrocarbons shipped each year remains constant at 1989 levels. Although overall traffic growth is anticipated for these chemicals, the incremental risk from increased shipments and the incremental cost of additional 105s are both proportional to traffic volume. Therefore, the *NPV* per tank car will not change. Third, it was assumed that the annual rate of car utilization, that is, the number of trips per car each year, remains constant regardless of the type of car used. In actuality, the higher value of the 105 might provide an incentive to operators and carriers to improve the efficiency of their use of tank cars, which would increase the *NPV* of replacing 111s with 105s. Finally, it was assumed initially that the train accident rate will remain constant. The rapid decline observed in the 1980s appears to be leveling off and unless there are technological breakthroughs in derailment prevention, declines of this magnitude are anticipated in the near future. The implications of removing the last assumption are discussed later. The following discussions of benefit estimation, cost estimation, and future cleanup costs describe how we estimated the factors in this equation.

BENEFIT ESTIMATION

The annual benefit (b) of replacing the 111s with 105s is the average saving associated with having to clean up a smaller expected number of spills each year over the lifetime of the replacement cars. To estimate the magnitude of this saving, the experience of the past decade was reviewed. There were 15 train accidents from 1980 through 1989 in which one of the 10 halogenated hydrocarbons was released from one or more damaged tank cars, involving a total of 41 tank cars. At least 35 other release incidents not caused by train accidents also occurred in this period, most of which involved much smaller spill quantities.

Data from the railroads indicate that 8 of these 50 incidents were especially costly to clean up. Six of the eight were caused

by train derailments and two were not (one involved a weld failure and the other a damaged bottom outlet that leaked). The most costly was the result of a derailment on the Illinois Central Railroad that took place on the outskirts of Livingston, Louisiana in 1982. The railroad has already spent over \$20 million to clean up the PERC that was absorbed into the soil and released into groundwater. Ongoing water treatment and site monitoring has been costing approximately \$25,000 per month. To date the total unadjusted cost of cleaning up the spilled halogenated hydrocarbons in these eight incidents is \$50.4 million. Remediation efforts are still ongoing for six of the eight incidents. The present value of the future cost of completing the cleanup at these sites is conservatively estimated to be \$5.0 million. On the basis of the recent Superfund experience, however, these costs are likely to increase beyond the current estimates (10-12).

To adjust the historical cleanup costs shown in Table 2(a) to 1990 dollars the railroads involved were asked to provide a detailed historical breakdown of the expenditures on these spills (the 1990 figures refer to ongoing remediation efforts from the earlier incidents). This was necessary to account for general inflation and changes in real costs. These costs apply only to incidents that occurred in the period 1980 through 1989. The most quantifiable change in real costs over the years since 1980 has been the more than 700 percent increase in the average cost of land disposal of soils contaminated with these chemicals (Figure 4). This cost has risen from approximately \$25 per ton in 1980 to approximately \$220 per ton 1990 (13). These values were used to adjust the annual cost for soil disposal in each year relative to the cost in 1990. The resulting adjustment factor ranged downward from 8.8 in 1980 ($\$220/\$25 = 8.8$) to 1.0 in 1990. Although average monitoring and treatment requirements and their resultant costs have experienced real increases over the past decade, we were unable to satisfactorily quantify the additional effect of these increases on the remediation cost of the specific sites under study. Therefore, all other remediation cost components were adjusted to 1990 dollars using a GNP index based on the general inflation rate; the values of this index increased monotonically from 1.0 in 1990 to 1.529 in 1980. Up to the end of 1990, the total cleanup cost due to spills of the 10 halogenated hydrocarbons in railroad transportation incidents that occurred in the period 1980 through 1989 is estimated to be about \$72.1 million in 1990 dollars, as shown in Table 2(b). With the addition of \$5.0 million, the present value of the future costs, the total becomes \$77.1 million. This estimate is conservative because it does not include all the litigation costs nor any of the real costs of increased site monitoring and more stringent contaminated soil removal standards, other than the unit cost of soil disposal. It also does not include the costs to parties other than the shipper, carrier, and car-owner.

To calculate the per carload liability over this period, the number of carloads of the ten halogenated hydrocarbons shipped from 1980 to 1989 was estimated by fitting a curve to the estimated actual carloads for the 3 years in Table 1 and extrapolating back over the preceding 7 years. This produced a total of 62,600 tank car-loads. Dividing the total of \$77.1 million by this number gives an average environmental cleanup liability of \$1,232 per carload. This per carload liability estimate then had to be adjusted downward to reflect the safer operating conditions in 1990 compared with the average con-

TABLE 2 CLEANUP COSTS (\$ THOUSANDS): (a) ACTUAL AND (b) ADJUSTED TO 1990 DOLLARS

Year	Soil Disposal	Air Stripped Water	Carbon Treated Water	Other Costs	Total
1980	152	4,833	0	844	5,829
1981	0	4,833	0	0	4,833
1982	1,285	4,834	541	393	7,053
1983	3,625	0	1,855	6,740	12,220
1984	0	5	3,184	403	3,592
1985	0	534	2,666	350	3,550
1986	0	1,812	781	715	3,308
1987	1,386	1,421	520	1,879	5,206
1988	0	202	368	639	1,209
1989	0	265	413	1,668	2,346
1990	0	367	372	540	1,279
Total	6,448	19,106	10,700	14,171	50,425

Year	Soil Disposal	Air Stripped Water	Carbon Treated Water	Other Costs	Total
1980	1,338	7,390	0	1,290	10,018
1981	0	6,737	0	0	6,737
1982	5,770	6,333	709	515	13,326
1983	*5,097	0	2,339	8,499	15,935
1984	0	6	3,872	490	4,368
1985	0	631	3,149	413	4,193
1986	0	2,086	899	823	3,808
1987	2,345	1,586	580	2,097	6,608
1988	0	218	397	690	1,306
1989	0	275	428	1,730	2,433
1990	0	367	372	540	1,279
Total	16,622	25,628	12,745	17,088	72,082
Percent	23%	36%	18%	24%	100%

* This value represents only a partial adjustment because of the unusually high unit cost of soil disposal paid for the 1983 Lake Charles incident.

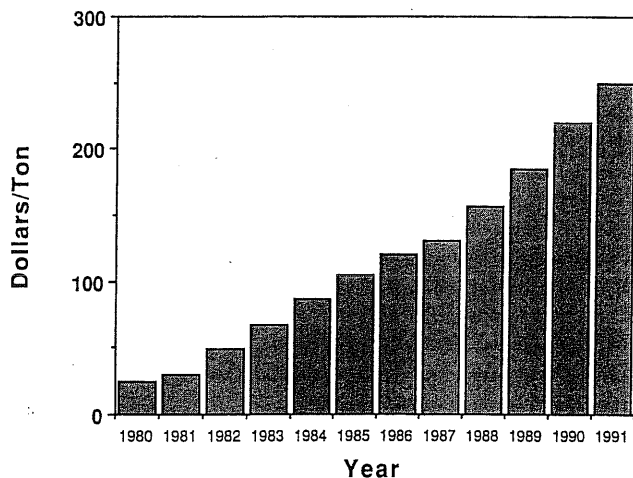


FIGURE 4 Cost of disposal of soil contaminated with halogenated hydrocarbons.

ditions over the 10-year period used as the basis for the cost calculations. Three aspects of rail transportation of hazardous material safety have improved over the period from 1980 to 1989: train accident rate, non-accident caused release rate, and tank car performance in accidents. The estimate of current liability had to be corrected to account for each of these. Thus, it was noted first that the 1989 train accident rate was 67 percent of the 10-year average (Figure 2). Second, it was determined that the 1989 rate of non-accident caused release incidents was 75 percent of the 10-year average (14). Third, calculations based on available data for tank cars indicated that the probability of release from an accident for damaged, non-insulated, general-purpose 111 tank cars averaged 0.25 over the period 1980 to 1989, compared with 0.225 for 1989 alone (8). Thus, on the basis of a relative difference of 10 percent, the 1990 accident-caused release probability for 111s damaged in accidents was estimated to be 90 percent of the 10-year average.

Recalling that 6 of the 8 incidents ($\frac{3}{4}$) were due to train accidents and the other 2 ($\frac{1}{4}$) were non-accident caused, the

total industry liability in 1990 associated with transporting these ten chemicals was estimated to be $[(\frac{3}{4} \times 67 \text{ percent} \times 90 \text{ percent}) + (\frac{1}{4} \times 75 \text{ percent})] \times \$1,232 = \$788$ per carload. Multiplying this figure by the 11,798 carloads in 1989 yields an estimated annual industry-wide liability of \$9.3 million due to the rail transportation of these chemicals.

Other things being equal, the average annual benefit of replacing the 111s by 105s is the portion of this cost that would be avoided because of the difference in the release probabilities for the 105 and the 111 tank car. This difference is reflected by the relative reduction in $P(R)$, the probability of a release in a train accident. Assuming that $P(D)$, the probability that a tank car is damaged in a train accident, is the same for both types of cars, the reduction in the conditional probability $P(R|D)$ is equal to the reduction in $P(R)$. The reason is that $P(R) = P(D) \times P(R|D)$ and the $P(D)$ values cancel out when the relative reduction in $P(R)$ is calculated. Given the estimates of 22.5 percent for $P(R|D)$ for non-insulated 111A100W1 tank cars, 10.7 percent for 105A300W tank cars, and 3.7 percent for 105A500W tank cars (8), the reduction in $P(R|D)$ is estimated to be $(22.5 - 10.7)/22.5 = 52.4$ percent for the 105A300W and $(22.5 - 3.7)/22.5 = 83.6$ percent for the 105A500W. The estimated annual benefit for the 105A300W is $\$9.3 \text{ million} \times 52.4 \text{ percent} = \4.9 million and for the 105A500W, it is $\$9.3 \text{ million} \times 83.6 \text{ percent} = \7.8 million . These are the annual, industry-wide liabilities that would be avoided by using the respective kinds of 105 specification tank cars to transport these chemicals, that is, they are the values of b in the NPV equation. In carload terms, these results mean that under current packaging practices, the estimated average liability per carload is \$788, which reduces to \$375 per carload for the 105A300W and \$129 per carload for the 105A500W. (Note that the calculation of the reduction in $P(R|D)$ treated all eight incidents as accident caused although two were not. This approach is reasonable, given that using 105s instead of 111s would have diminished the likelihood of occurrence in one case and virtually eliminated it in the other.)

COST ESTIMATION

The variable cost of transportation, that is, the cost per mile, is about the same for 111s as for 105s, but the reduced capacity of the heavier 105A500W means that more carloads are required to transport the same quantity of chemical. Therefore,

the incremental average annual transportation cost (c_t) associated with replacing the 111s by 105s was estimated by taking the product of three factors: the average cost per shipment in either type of car, the percentage increase in the number of cars required, and the current annual number of carloads shipped.

To estimate the first factor, the 1988 Sample of Carload Waybill Statistics of the Interstate Commerce Commission (ICC) for U.S. terminations was used, supplemented by AAR TRAIN II data for Canadian terminations, to determine that the average length of haul for the 10 halogenated hydrocarbons was about 850 mi. Then, using the ICC's Uniform Rail Costing Model, it was determined that, for a tank car having a capacity less than 22,000 gallons traveling 850 mi, the average variable cost per shipment is \$1,606.

To estimate the second factor, a tank car size-and-weight program developed by Union Tank Car Company was used. The size of a tank car is often optimized for individual commodities as a function of the commodity's density. The objective is to maximize the ratio of lading to tank car light weight (tare), so that the loaded car does not exceed the current maximum AAR interchange limit of 263,000 lb for weight on rails. This must be accomplished within the constraints imposed by various DOT and AAR specifications, including, among other things, clearances, tank thickness, and car length. For each of the 10 halogenated hydrocarbons the optimum size and weight of a 111 tank car and a 105 tank car and the percentage loss in capacity because of the heavier weight of the 105 was determined. As Table 3 shows, the results ranged from about 7.2 percent for ethylene dibromide, the heaviest of these chemicals, to 11.2 percent for ethylene dichloride, the lightest. Then, weighting each of these percentages by the corresponding number of 1989 carloads, we determined that the average loss in capacity would be 10.5 percent. This means that about 11.7 percent more shipments would be required to move the same quantity of these chemicals, because the number of shipments is inversely related to the capacity and $1/(1 - 0.105) = 1.117$.

The value of the third factor is 11,798 carloads. Hence the product of the three factors is $\$1,606 \times 0.117 \times 11,798 = \2.22 million . This is the estimated value of c_t under the assumptions of no real increase in the average cost per shipment, no growth in total traffic, and optimally size tank cars. Analysis of the actual loading practices of these products indicates that if current inefficiencies in tank car use were elim-

TABLE 3 CAPACITIES OF NONINSULATED 111A100W1 TANK CARS AND OPTIMIZED 105A500W TANK CARS

CHEMICAL	Density (lbs/gal)	Capacity (gallons) 111A100W1	Capacity (gallons) 105A500W	Percent Reduction In Capacity
Carbon tetrachloride	13.22	15,803	14,338	9.27
Chlorobenzene	9.24	21,890	19,186	12.35
Chloroform	12.41	16,764	15,123	9.79
Dichlorobenzene	10.90	18,876	16,819	10.90
Ethylene dibromide	18.16	11,713	10,873	7.17
Ethylene dichloride	10.45	19,607	17,401	11.25
Methyl chloroform	11.19	18,432	16,464	10.68
Methylene chloride	11.02	18,690	16,671	10.80
Perchloroethylene (PERC)	13.54	15,453	14,049	9.09
Trichloroethylene (TCE)	12.16	17,083	15,380	9.97
PERC/TCE mixture	12.85	16,053	14,544	9.40

WEIGHTED AVERAGE

10.54

inated, the 11.7 percent weight penalty would be reduced to approximately 7.5 percent.

As far as fixed costs are concerned, replacing the 111s by 105s will require two major capital expenses: the net cost of acquiring 105s and the cost of modifying the terminals for top unloading of 105s. The second expense is necessary because general-purpose 111s are usually unloaded through bottom outlet valves but these are prohibited on the 105s.

The acquisition cost (c_a) is the difference between the total cost of replacing the existing 111s with new 105s, and continuing to use the existing 111s. According to recent industry estimates, the price of a new 105A500W tank car is approximately \$88,000, while a new general-purpose 111 costs approximately \$58,000. Assuming that the current rate of car utilization continues at nine trips per year, the number of 111s in question is $11,798/9 = 1,311$ and the number of 105s required to replace them is $1,311 \times (1 + 0.117) = 1,464$.

The cost of continuing to use the existing 111s is the present value of the cost of replacing $\frac{1}{30}$ of the 1,311 cars each year due to attrition. Every such replacement will require a new car to be purchased but will yield a salvage value of the old car equal to 10 percent of the new cost, for a net cost of 90 percent of \$58,000, or \$52,200. Hence the total annual cost is $\frac{1}{30} \times 1,311 \times \$52,200 = \$2.28$ million. Over 30 years, the total present value of this cost is \$21.49 million. The final value of c_a depends on the fate of the existing cars that are displaced from halogenated hydrocarbon service. There are two possible extremes: either all the cars are scrapped or they are all sold or transferred into other service. If they are scrapped, c_a is equal to the cost of the new 105s minus the scrap value of the 111s minus the present value of the cost of attrition-based renewal of the 111 fleet described previously. The calculation is as follows: $(1,464 \times \$88,000) - (1,311 \times \$5,800) - \$21.49$ million = \$99.74 million. Alternatively, if all of the cars are sold or transferred, the AAR replacement value for a 15 year-old car (the average age of cars in this service) minus the cost of cleaning is used. Under this scenario, the calculation changes to $c_a = (1,464 \times \$88,000) - [1,311 \times (\$31,900 - \$1,000)] - \21.49 million = \$66.83 million. Assuming that half of the current fleet would be scrapped and half would be sold or transferred into other service, it was estimated therefore that the average value of c_a would be \$83.28 million.

The cost of terminal modification (c_m) derives from the fact that many of the existing terminals which receive these products and are not equipped for top unloading would have to be modified to handle the 105s. The Chemical Manufacturers Association (CMA) estimates that the average cost of retrofitting a terminal for this purpose would be between \$10,000 and \$20,000. To estimate the number of terminals, we used 1989 AAR TRAIN II data to determine that the shipments of the ten halogenated hydrocarbons went to about 140 destinations in the U.S. and Canada. Some of the terminals at these locations may already have top unloading capability, whereas others may have multiple racks within the same facility. Allowing for this uncertainty and the fact that customer locations might change in the future, requiring some additional cost in constructing unloading facilities, we estimated that 200 terminals would have to be modified. The median value of the cost figures provided by CMA is \$15,000 per terminal, resulting in an estimated value for c_m of $200 \times \$15,000 = \3 million.

FUTURE CLEANUP COSTS

The rate of future increases in cleanup costs will depend on a number of factors, but it is expected that the influence of regulatory requirements will continue to dominate. The response to spills of hazardous substances that is currently required by the federal government comes under the provisions of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), which was revised in 1990 to reflect the 1986 amendments to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). CERCLA requires the Environmental Protection Agency (EPA) to define cleanup criteria known as "applicable or relevant and appropriate requirements" (ARARs). Depending on the hazardous substance and the specifics of the site, an ARAR may call for in situ remediation or removal and treatment of contaminated soil and groundwater. Effective in 1992, federal law will generally prohibit the disposal in landfills of soil that has been contaminated with halogenated hydrocarbons. More expensive alternative treatment methods such as high-temperature incineration or vitrification will usually be required when soil contaminated with halogenated hydrocarbons must be disposed of. Water treatment is also expected to become considerably more expensive within the next few years because of Title III of the Clean Air Act of 1990 (CAA). The most commonly used technique for treating contaminated water, known as air stripping, in which the volatile contaminant is removed from the water and released into the atmosphere, will no longer be allowed for the halogenated hydrocarbons. More costly methods will be required in which air pollution control devices are employed or activated carbon filtration is used. The unit cost of these methods can range from two to ten times the unit cost of air-stripping (15,16). In addition, state requirements for site remediation continue to become more stringent, driving cleanup expenses still higher.

These recent regulatory and legislative developments mean that contaminated soil and water, the two principal disposal and treatment components resulting from spills of these chemicals, will be much more expensive in the near future. Soil incineration is considerably more expensive than disposal in a hazardous waste landfill (17). A survey of major hazardous waste disposal firms conducted for the AAR (13) found that the average cost of incineration in 1990 was 5.5 times greater per unit of soil disposed than the average cost of landfilling. Analysis of the cleanup expense showed that soil disposal accounted for 23 percent of the total cost of site remediation in 1990 dollars [Table 2(b)]. To calculate the real rate of increase due to the full implementation of the land ban in 1992, we multiplied this fraction by 5.5 in year one. The result was a 104 percent increase in the overall cost of remediation ($r_1 = 1.04$). In order to quantify the effect of the CAA on remediation costs we determined from Table 2(b) that approximately 36 percent of the total cost of remediation was accounted for by water treatment using air stripping.

EPA has not yet promulgated the regulations mandated by the CAA prohibiting this method of water treatment. Its timetable for implementation of Title III ranges from three to seven years after its passage in 1990, depending on the chemical (18). A median value of five years and a four-fold increase in water treatment costs was assumed. The impact will be an

additional 52 percent increase in the overall liability in year five ($r_5 = 0.52$). As mentioned in the section describing benefits, other cost factors are also expected to undergo real increases because of more stringent cleanup standards, greater monitoring requirements, additional third party expenses, and social inflation (19). However, because the authors were not able to satisfactorily quantify these factors, $r_j = 0$ for all other years was assumed.

RESULTS

Summarizing the estimates of the factors in the benefit-cost equation, $b = \$7.8$ million, $c_t = \$2.2$ million, $c_a = \$83.3$ million, $c_m = \$3.0$ million, $r_1 = 1.04$, $r_5 = 0.52$, and all other $r_j = 0$. The discount rate i was assumed to be 0.10, based on the 1988 ICC value of 10 percent for the before-tax real cost of capital. The resulting *NPV* is \$94.7 million. Dividing by 1,464, the number of tank cars required, the corresponding *NPV* per 105A500W tank car is \$64,701. A similar analysis was conducted for the 105A300W by substituting the following values in the formula: $b = \$4.9$ million, $c_t = \$1.0$ million, and $c_a = \$53.8$ million. The total *NPV* for conversion to 105A300W tank cars is thus \$60.5 million. Division of this number by 1,380, the estimated number of 105A300Ws that would be required, yields an *NPV* per tank car of \$43,861.

The effect that a reduction in train accident rate would have on the *NPV* was also estimated. To make these calculations, we inserted the term $(1 - a)^n$ ahead of b in the formula, where a represents the annual percentage decline in accident rate. A 1 percent or 2 percent compounded annual reduction in the train accident rate sustained over the 30-year period resulted in respective *NPVs* of \$75.8 million and \$59.3 million for the 105A500W and \$48.6 million and \$38.3 million for the 105A300W. For either of the two 105 specifications, a 7 percent annual reduction in train accident rate would have to be sustained over the 30-year period to yield an *NPV* of zero (Figure 5). These results do not reflect the additional costs

and benefits associated with changes in the accident rate. The effect that the 11.7 percent increase in the number of carloads would have on the probability of accident involvement was not quantified. Although the number of cars derailed increases with number of car-miles, the actual functional relationship between these two variables depends on the accident cause. For example, the most likely impact of more cars would be longer trains. The number of cars derailed per derailment is positively correlated with train length but the rate of change in the functional relationship is much less than one (20). The influence of more tank cars would also be counteracted somewhat by smaller expected spill sizes because of the lower capacity and greater strength of the 105s.

The car utilization rate assumed in the model was 9 trips per year, which is lower than that reported by several major chemical shippers. The *NPV* if 105s are used is a positive function of car utilization efficiency because the greater the number of trips per year, the fewer the number of cars required, and the lower the corresponding value of c_a (Figure 6). Better car utilization is in the mutual interest of both industries because it lowers the capital outlay required of the shippers, thereby improving the cost-effectiveness of more secure tank cars while providing industry and the public with the benefits of fewer spills. To achieve better utilization, the railroads can assist by moving tank cars more expeditiously and the chemical shippers can contribute by providing incentives to their customers to unload and return cars promptly.

SUMMARY AND CONCLUSIONS

The 10 halogenated hydrocarbons considered in this analysis are currently transported in general-purpose tank cars because of their relatively low acute hazard to human health and safety. As the general awareness and understanding of environmental hazards and the health effects of chronic exposure to potential carcinogens have increased, so have the requirements for environmental cleanup of these chemicals.

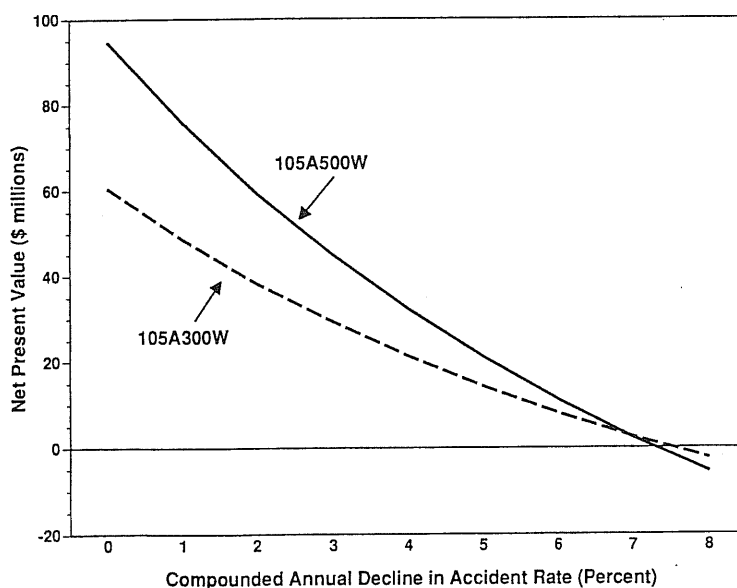


FIGURE 5 Effect of train accident rate on *NPV*.

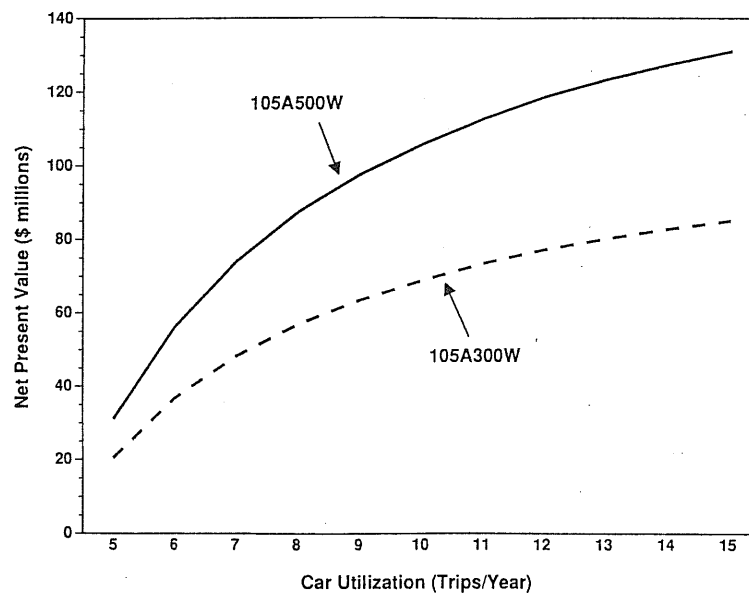


FIGURE 6 Effect of car utilization on NPV.

But transportation packaging practices have not kept pace with the environmental and economic impacts of these spills. Another hazard must be considered along with the more traditional hazards of acute toxicity, flammability, explosivity, and corrosivity. This hazard, which is referred to here as environmental sensitivity, needs to be factored in when evaluating the transportation risk of chemicals.

In deciding how to best respond to this need, analogies with packaging practices for other chemicals that rank highly on their respective hazard axes are appropriate. Beginning in 1918, the railroads and the car-building and chemical industries recognized that there was a need to "over-design" tank cars carrying chemicals that "if not contained were dangerous to life" (21). This was the reason for the development of the Type V tank car (precursor to the current 105) for transportation of chlorine and sulphur dioxide, and later the 105 car for tetraethyl lead. Subsequent experience with 105 tank cars carrying acutely toxic or flammable materials over the years has been excellent. Because of the wide range in hazards, this degree of over-packaging is not necessary for all chemicals, but the study results suggest that in the case of the 10 selected halogenated hydrocarbons, switching to 105s would be a cost-effective means of reducing risk.

ACKNOWLEDGMENTS

A number of people have contributed to the authors' understanding of this subject. The authors are grateful to the following individuals from the railroad, chemical, and car-building industries for helpful discussion and information: P. C. L. Conlon, B. J. Damiani, J. W. Fleshman, T. A. Gudiness, R. J. Holden, P. G. Kinnecom, D. J. Pasternak, L. W. Papple, E. A. Phillips, R. E. Phillips, M. J. Rush, M. P. Stehly, C. E. Taylor, A. S. Rivers, K. E. Wolfe, J. E. Waggener, and W. J. Woodall. T. P. Warfield, Q. Huang, and P. B. Williams assisted with the data analysis. Special thanks to the members of the AAR Environmental Committee, Bureau of

Explosives Steering Committee, and Tank Car Committee and railroad staff who provided data and insight.

REFERENCES

1. K. Wolf and F. Camm. *Policies for Chlorinated Solvent Waste*. Report R-3506-JMO/RC, RAND Corp., Santa Monica, Calif., June 1987.
2. H. H. Russell, J. E. Matthews, and G. W. Sewell. Remediation of sites contaminated with TCE. *Remediation*, Vol. 1, no. 2, 1991, pp. 167-183.
3. P. H. Abelson. Volatile Contaminants of Drinking Water. *Science*, Vol. 247, no. 4939, 1990, p. 141.
4. A. E. Harvey, P. C. Conlon, and T. S. Glickman. *Statistical Trends in Railroad Accidents*. Publication R-640, Association of American Railroads, Washington, D.C., Sept. 1987.
5. Association of American Railroads. *Railroad Facts*, Washington, D.C., Annual, 1980-1989.
6. E. A. Phillips and H. Role. *Effectiveness of Shelf Couplers, Head Shields and Thermal Shields on DOT 112(114) and 105 Tank Cars*. Publication R-610, Association of American Railroads, Chicago, June 1985.
7. E. A. Phillips. *Analysis of Aluminum Tank Cars Damaged in Accidents 1965-1986*. Publication R-749, Association of American Railroads, Chicago, March 1990.
8. E. A. Phillips and C. P. Barkan. *Open Memoranda on DOT 111A and 105A Tank Cars Preliminary Analyses P-09-1-1, P-10-1-2 and P-05-1-3*. Association of American Railroads, Chicago, April-May 1990.
9. General American Transportation Corporation. *Tank Car Manual*. 5th Ed., Chicago, Ill., 1985.
10. *SUPERFUND: Cost Growth on Remedial Construction Activities*. General Accounting Office, Resources, Community and Economic Development Division, Feb. 1988.
11. T. L. Richardson, P. Dappen, and M. C. Ray. "Estimated versus final costs on hazardous and toxic waste remediation projects." *Proceedings of Superfund '90*, HMCRI, Silver Spring, MD, pp. 230-235, 1990.
12. B. R. Schroeder. "Cost inaccuracies in Superfund projects: Strategies for building better estimates." *Proceedings of Superfund '90*, HMCRI, Silver Spring, MD, pp. 236-240, 1990.
13. Resource Consultants, Inc. *Cost analysis: Disposal of soils contaminated with chlorinated hydrocarbons*. RCI Project 1-3221, Brentwood, TN, March 1991.

14. Bureau of Explosives. *Annual Report of Hazardous Materials Transported by Rail*. Association of American Railroads, Washington, D.C., Annual 1980-1989.
15. J. Q. Adams and R. M. Clark. "Evaluating the costs of packed-tower aeration and GAC for controlling selected organics." *American Water Works Association Journal*, vol. 83, no. 1, 1991.
16. Environmental Protection Agency. *Baseline and Alternative Waste Management Cost Estimates for Third Landban Disposal Restrictions*, October 1989.
17. Environmental Protection Agency-Office of Policy Analysis. *1986-1987 Survey of Selected Firms in the Commercial Hazardous Waste Management Industry*, March 1988.
18. Environmental Protection Agency-Office of Air and Radiation. *Implementation Strategy for the Clean Air Act Amendments of 1990*, January 1991.
19. K. E. Wolfe. "An examination of risk costs associated with the movement of hazardous materials." *Proceedings of the 25th Annual Meeting of the Transportation Research Forum*, vol. 25, pp. 228-240, 1984.
20. Delcan. *Rail Transportation of Dangerous Goods: Relationship Between Train Speed and Incidence and Severity of Accidents*. The Toronto Area Rail Transportation of Dangerous Goods Task Force, December, 1987.
21. B. R. Schroeder. "Cost inaccuracies in Superfund projects: strategies for building better estimates." *Proceedings of Superfund '90*, HMCRI, Silver Spring, Md., pp. 236-240, 1990.

Publication of this paper was sponsored by Committee on Transportation of Hazardous Materials.