RISK-BASED FINANCIAL ASSURANCE FOR TRANSPORT OF LOW-LEVEL RADIOACTIVE WASTE

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ABSTRACT

The purpose of this paper is two-fold: (1) assess the risks associated with the transportation of low-level radioactive waste (LLRW) in New York State; and (2) evaluate financial assurance requirements to cover those risks. The risk assessment uses as inputs characterizations of the following: (1) waste shipments by vehicle category (i.e., type of vehicle); and (2) environmental settings by generic route. Once LLRW shipments and environmental settings have been characterized, the risk assessment proceeds to analyze potential events (e.g., small accident enroute) and their consequences (e.g., dispersion of released materials and subsequent human exposure) for each combination of vehicle category and generic route (i.e., transport configuration).

Finally, for each transport configuration, the risk assessment estimates the probability and magnitude of corrective action costs and third-party compensation costs attached to the consequences of each event, and combines these estimates with the estimates of the probability of each event to construct a cost curve for corrective action, third-party compensation, and combined liabilities. Combined liabilities are the sum of corrective action costs and third-party compensation costs when applicable. Using the cost curves, coverage levels are derived by specifying a not-to-be-exceeded likelihood that costs in a given year will exceed the coverage level.

INTRODUCTION

This paper summarizes the approach and findings of a report prepared by ICF Incorporated under the direction of the Bureau of Radiation, New York State Department of Environmental Conservation (NYSDEC or the Department), in support of the Department's regulations for LLRW transport.**

The risk analysis characterizes the potential for liability costs associated with bodily injury, property damage, and environmental impairment resulting from LLRW transport. For purposes of the financial assurance requirements, potential liability costs are grouped into two categories: corrective action costs and

Corrective action costs include the costs of cleanup of property and the environment. Third-party compensation costs include the costs of bodily injury (e.g., medical treatment) and of economic loss due to property damage (e.g., loss of resale value) or environmental impairment (e.g., loss of recreational value).

OVERVIEW OF METHODOLOGY

The risk assessment uses ICF's Bodily Injury and Property Damage Assessment Model (BIPDAM), modified and run to reflect the specific characteristics of LLRW generation and transportation in New York State. As illustrated in the flowchart of Fig. 1, the risk assessment addresses the following five groups of questions:

(1) Vehicle categories and waste shipments: is it possible to group transport vehicles into a finite number of categories? What are typical LLRW shipments in each vehicle category?

(2) Generic routes and environmental settings: since the LLRW disposal facility has not yet been sited, is it

possible to construct different generic routes for different general locations of the site? What are the typical environmental settings along each generic route?

(3) Events: what can go wrong and how likely is it? More specifically, what types of events, accident-related and

*New York State Department of Environmental Conservation, 'Risk Assessment and Financial Surety Requirements Analysis for Transportation of Low-Level Radioactive Waste in New York State,' in: Volume II of the Generic Environmental Impact Statement for Promulgation of 6 NYCRR Part 381: Regulations for Low-Level Radioactive Waste Transporter Permit and Manifest System, prepared by ICF Incorporated, February 1988.

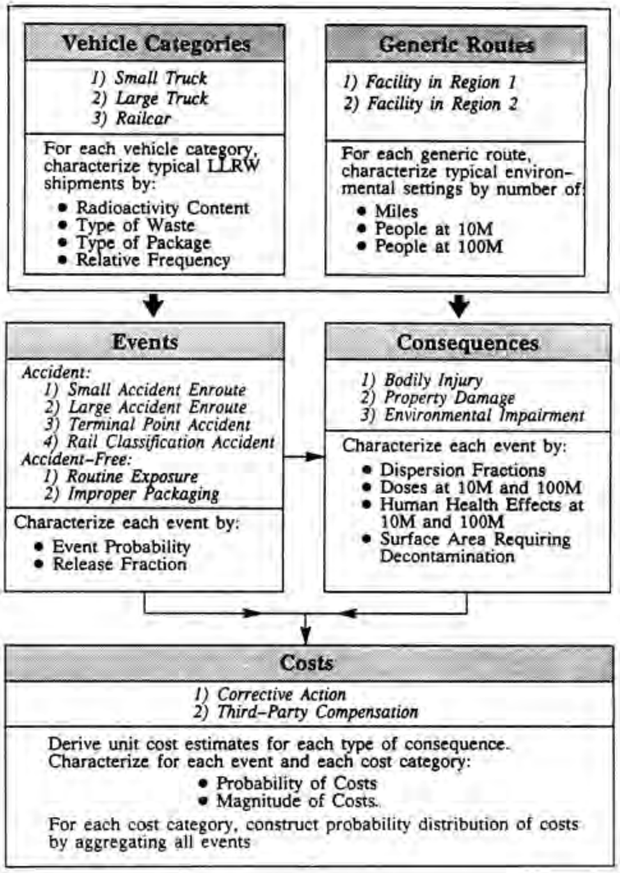


Fig. 1. Risk Assessment Flowchart.

accident-free, could occur that could result in adverse radiological and non-radiological impacts?

(4) Consequences: what are the potential consequences of each event on people, property, and the environment?

(5) Costs: what are the potential costs of corrective action and third-party compensation attached to these consequences? How can these potential costs be aggregated over all applicable events to summarize the risk picture for each transport configuration?

To answer these questions, the risk assessment uses best estimates of relevant factors to derive one cost curve for each transport configuration (i.e., each combination of vehicle category and generic route). Best estimates are derived from existing data when available or by using best professional judgment. Because this analysis does not explicitly evaluate uncertainty, it errs on the conservative side without compromising the reasonableness of the results when using best professional judgment.

This approach provides a basis for determining financial assurance coverage level requirements. Coverage levels are derived by specifying the not-to-be-exceeded likelihood (per year per vehicle) that potential costs would exceed these coverage levels. The not-to-beexceeded likelihood level is not an abstract concept. It is a tool that the Department can use to set coverage requirements at adequate levels to ensure that these levels would not be exceeded with a certain probability.

The following sections accomplish three tasks: (1) outlining the approach used to answer the five groups of questions above; (2) describing the interrelationships between the various aspects of the overall risk assessment; and (3) summarizing the intermediate and final results.

An initial screening of transporters indicates there are basically three vehicle categories that can be assessed and regulated separately for financial assurance: (1) small trucks (i.e., less than or equal to 10,000 pounds total gross weight); (2) large trucks (i.e., greater than 10,000 pounds total gross weight); and (3) railcars.

The risk assessment identifies five typical LLRW shipment profiles in New York State. For each vehicle category, each typical shipment profile is characterized in terms of the following: (1) type of waste (e.g., institutional and industrial biowaste); (2) type of package (e.g., steel drums or boxes); (3) radioactivity content (in curies per shipment); and (4) relative frequency among all LLRW shipments (in

TABLE I

Characteristics of Typical LLRW Shipments[a]

Shipment Profile[c]	LLRW Class	Package Type	Curies per Shipment[b] by Vehicle Category: Small Truck	Large Truck	Railcar	Frequency: Number	Percent
1	A	Drum/box	4.6	7.9	16	63	41
2	A	Cask	32	56	110	62	41
3	B	Cask	84	150	290	21	13
4	C	Cask	75	1,300	2,600	6	4.3
5	C	Cask	21,000	21,000	42,000	1	0.7

[a] Based on data from 153 manifests for LLRW transport in New York State for the first ten months of 1987.

[b] For small and large trucks, the upper 95th percentile value is used. For railcar, an assumption is made that two large truck shipments can be placed on a railcar.

[c] 1 - Institutional and industrial biowaste.
2 - Pressurized water reactor (PWR) ion exchange resin waste.
3 & 4 - Boiling water reactor (BWR) ion exchange resin waste.
5 - Non-fuel irradiated reactor component waste.

percentage). Characterization of shipment profiles by vehicle category is summarized in Table I.

This analysis assesses two generic routes, corresponding to two regions of New York State (see Fig. 2). The distinction between these two regions of the state will be useful when a disposal facility site is selected. At that time, the state may focus on the financial assurance requirements for the generic route applicable to the site. If the facility is sited in Region 1, then LLRW carriers will on average transport waste on a route similar to generic Route 1. Generic Route 2 applies if the LLRW disposal facility is located in Region 2. The risk assessment separately considers each of the six transport configurations defined by combinations of vehicle category and generic route (e.g., small truck using generic Route 1).

The risk assessment identifies six typical environmental settings (e.g., urban setting) along highway and railway routes in New York State. For each generic route, each typical environmental setting is characterized in terms of the following: (1) number of miles along the route; (2) people at a distance of less than 10 meters; and (3) people at a distance of 100 meters. Table II shows the frequency of each environmental setting alone each generic route.

The risk assessment considers four categories of event types associated with LLRW transport: (1) radiological accident-related (i.e., small and large accidents enroute, terminal point accident, and railway classification accident); (2) radiological accident-free (i.e., routine exposure, improper packaging, and natural catastrophes); (3) nonradiological accident-related (i.e., highway and railway

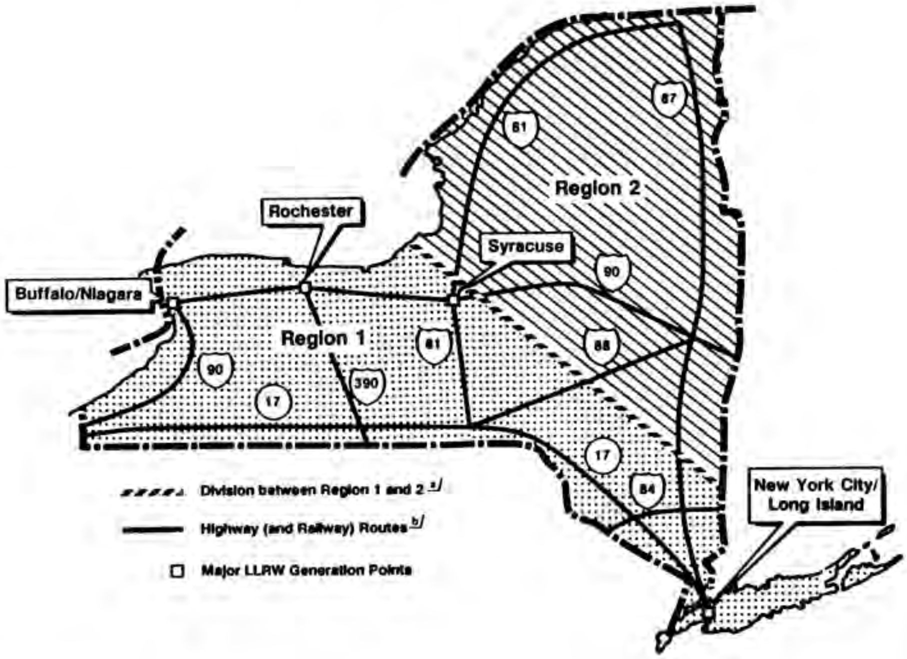
TABLE II

Generic Route Characteristics

Environmental Setting	Generic[a] Route 1: Miles	Percent	Generic[b] Route 2: Miles	Percent
Urban	10	5	11	4
Suburban	32	16	66	25
Farmland	49	25	51	20
Woodland	48	24	79	30
Park	17	8	17	7
Rivers/Lakes	43	22	35	14
Total:	199	100	259	100

[a] Facility located in Region 1 of New York State.

[b] Facility located in Region 2 of New York State.



[a] If the disposal facility is sited in Region 1, then LLRW carriers will, on the average, transport waste on a route similar to generic Route 1. Generic Route 2 applies if the LLRW disposal facility is located in Region 2. See text for further details.

[b] With the exception of I-84 the major highway routes generally are paralleled by major railway routes.

Fig. 2. Major LLRW Generation Points and Possible Transportation Routes in New York State.

fatalities); and (4) non-radiological accident-free (e.g., pollution, road and rail wear).

The analysis estimates the probability that each of the radiological accident-related events will occur in each environmental setting, and the fraction of LLRW released due to the event. The probability of a releasing accident-related event is a function of the probability of an accident involving the vehicle and the probability of a release given that the accident has occurred. The latter probability depends on the type of accident and type of package. Table III lists the accident and release probabilities used to derive event probabilities.

Release fractions also are a function of the type of accident and the type of package used (see Table III). The release fraction multiplied by the shipment radioactivity content gives the source term used in the consequence analysis; that is, the curies at source are defined in this analysis as the amount of radioactivity released due to the accident and therefore available for dispersion in the environment. The fraction of this source term actually dispersed is addressed in the consequence analysis.

CONSEQUENCES

Using input from the events analysis (e.g., fraction of curies released) and from characterizations of vehicle categories (e.g., type of waste and radioactivity content of shipment) and generic routes (e.g., number of people potentially exposed), the assessment addresses the potential consequences to population, property, and the environment due to LLRW releases. The consequence analysis estimates the amount of curies dispersed of each isotope as a function of the source term (i.e., the amount of curies released). Dispersion fractions range from 0.001 (e.g., Co-60) to 0.5 (e.g., H-3). Using reasonably conservative generic assumptions, the consequence analysis converts the following: (1) the estimate of curies dispersed into human exposure at less than 10 meters and at 100 meters; (2) the exposure dose estimates into likelihoods of different types of bodily injury (i.e., chronic effects such as cancer, and acute effects such as minor burns); and (3) the estimate of curies dispersed into an estimate of the surface area of property or environment requiring cleanup.

For the less than 10-meter distance, non-zero dose estimates range from 0.67 rems per person (small accident, small truck, Shipment Profile 1) to 260 rems per person (large accident, railcar, Shipment Profile 5). For the 100-meter distance, non-zero dose estimates range from

TABLE III

Summary of Accident Characteristics

Characteristics of Event Type	Event Type: Small Accident Highway	Small Accident Railway	Large Accident Highway	Large Accident Railway	Terminal Point Accident	Railway Classifi. Accident
Accident Probability[a]	4.0E-6	7.2E-6	4.0E-7	7.2E-7	6.9E-3	4.3E-5
Release Probability (per accident):						
Drums/boxes[b]	4.2E-1	4.2E-1	8.4E-1	8.4E-1	4.2E-1	4.2E-1
Casks containing Class A or B wastes[c]	2.3E-1	2.3E-1	4.6E-1	4.6E-1	2.3E-1	2.3E-1
Casks containing Class C waste[d]	6.4E-2	6.4E-2	1.3E-1	1.3E-1	6.4E-2	6.4E-2
Release Fraction:						
Drums/boxes[b]	2.8E-2	2.8E-2	2.8E-1	2.8E-1	2.8E-2	2.8E-2
Casks containing Class A or B wastes[c]	8.2E-3	8.2E-3	8.2E-2	8.2E-2	8.2E-3	8.2E-3
Casks containing Class C waste[d]	2.8E-3	2.8E-3	2.8E-2	2.8E-2	2.8E-3	2.8E-3

[a] For highway and railway accidents, accident probability is per mile traveled. For terminal point accidents, accident probability is per terminal point (two terminal points per shipment). For railway classification accidents (i.e., accidents during the enroute transfer of a railcar from one locomotive to another) accidents, accident probability is per classification (three classifications per shipment).

[b] Shipment Profile 1.

[c] Shipment Profiles 2 and 3.

[d] Shipment Profiles 4 and 5.

8.1×10^{-5} rems per person (small accident, small truck, Shipment Profile 1) to 0.11 rems per person (large accident, railcar, Shipment Profile 5). The probability of suffering a chronic effect is estimated at 10^{-3} per rem per person. Nonzero contaminated surface area estimates range from 890 square meters (small accident, small truck, Shipment Profile 3) to $8.7 \times 10^{+5}$ square meters (large accident, railcar, Shipment Profile 5).

COSTS

Using results from the events and consequence analyses, the assessment estimates the potential costs associated with each event and groups these costs into two categories: corrective action costs and third-party compensation costs. The cost analysis follows three steps. First, unit cost estimates are derived for each type of bodily injury, property damage, and environmental impairment, and then grouped into the two categories needed for financial assurance requirements (i.e., corrective action costs and third-party compensation costs). Second, the unit cost estimates are applied to the results of the events and consequence analyses to estimate the probability and magnitude of costs attached to each event. Third, for each transport configuration, a cost curve is constructed for corrective action, third-party compensation, and combined liabilities by compiling estimates of probability and magnitude of costs for each event. Combined liability costs are the sum of corrective action costs and third-party compensation costs when applicable (some events could result in corrective action costs but not in third-party compensation costs, and vice versa).

As seen in the example cost curves in Fig. 3, each cost curve summarizes the potential costs associated with transport of LLRW under the conditions represented by the configuration in question. Potential costs are summarized in the form of a cost curve where the y axis is the likelihood of exceeding specified costs, and the x axis is the costs. In other words, the cost curve indicates, for each possible cost outcome, the likelihood (i.e., probability per year per vehicle) that a given cost would be exceeded.

For convenience, likelihood estimates are reported on a logarithmic scale. A likelihood of 10 corresponds to a 100 percent probability of occurrence per year per transport vehicle, while a likelihood of 0 represents a probability of occurrence of 10^{-10} (i.e., one in ten billion) per year per vehicle. More generally, likelihood (L) is defined as a function of probability (p) per year per vehicle as follows:

$$L = 10 + \log_{10}(p). \qquad (1)$$

For example, basing coverage levels on a per year per vehicle likelihood of exceedance of 8 means that there is, in a given year, a probability of one in a hundred that potential costs associated with LLRW transport by one vehicle would exceed the coverage level. Table IV presents likelihood values, corresponding probabilities of occurrence, and examples.

Cost curves are constructed by compiling the individual cost results (magnitude and likelihood) obtained for each event applicable to the transport configuration. For each transport configuration and each cost category, all pairs of likelihood and cost attached to all events are sorted in decreasing order of cost. For each cost estimate, the cumulative probability that this cost would be exceeded is then calculated by adding up the individual probabilities associated with costs greater than or equal to this cost estimate. The resulting cost curve illustrates the relationship between costs and the likelihood that these costs would be exceeded (on a per year per vehicle basis).

Financial assurance coverage levels can be based on the cost results of the risk assessment. This is done by specifying a not-to-be-exceeded likelihood that costs would exceed the corresponding coverage level. With the acceptable likelihood level specified, the derivation of coverage levels is equivalent to finding the cost on the curve corresponding to the likelihood of exceedance. This amount is by definition the minimum coverage necessary to ensure, with a certain probability, that costs would not exceed the amount of coverage specified.

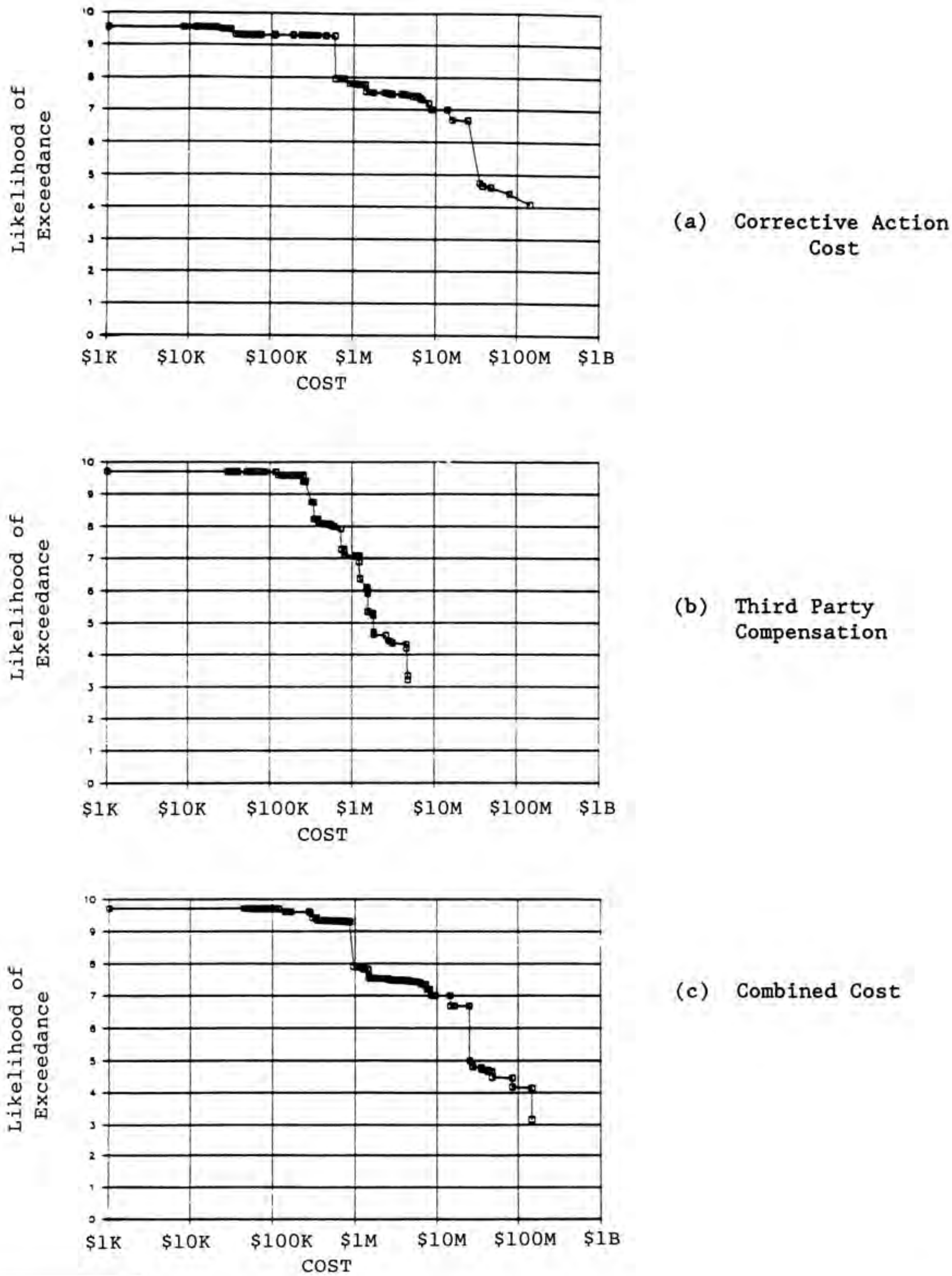
Table V presents coverage levels for four values of the acceptable likelihood of exceedance: 8 (i.e., one expected occurrence every 100 years), 7.6 (i.e., one every 250 years), 7.3 (i.e., one every 500 years), and 7 (i.e., one every 1,000 years). For example, for a small truck using either Route 1 or Route 2, a coverage level of $1 million has a one in 100 chance of being exceeded in any particular year.

Likelihood, cost, and coverage level estimates are all on a per year per vehicle basis. If a carrier has more than one vehicle licensed for transport of LLRW, then the aggregate coverage levels for this carrier are not a simple multiplication of the per vehicle coverage levels by the number of licensed vehicles. This property results from the probabilistic nature of the costs involved. More analysis would be needed to convert the aggregate coverage levels per vehicle to aggregate coverage levels per carrier when the carrier has more than one vehicle licensed to transport LLRW.

The following are conclusions based on the results of the risk assessment:

(1) Coverage levels are fairly insensitive to the disposal facility site location (i.e., Region 1 or 2) for a likelihood of exceedance equal to 7 or 8.

(2) Coverage levels vary considerably with the disposal facility site location for a likelihood of exceedance between 7.3 and 7.6.



[a] Units for likelihood of exceedance are explained in the text. Costs are in 1987 $.

Fig. 3. Cost Curves for Small Truck, Generic Route 1.[a]

TABLE IV

Likelihood Values, Probabilities of Occurrence, and Examples

Likelihood Value	Probability of Occurrence	Example of Probability
10	1.0	Death from any cause during lifetime.
9	10^{-1}	Non-fatal cancer from any cause during lifetime.[a]
8	10^{-2}	Death from auto accident during lifetime.[b]
7	10^{-3}	Killed by fire during lifetime.[b]
6	10^{-4}	Death from animal bite or sting during lifetime.[b]
5	10^{-5}	Death from smoking 20 cigarettes.[b]
4	10^{-6}	Cancer from eating 40 table-spoons of peanut butter.[b]
3	10^{-7}	Killed by lightning in any given year.b
2	10^{-8}	Killed by tornado in any given week.b
1	10^{-9}	Killed by flood in any given day.b
0	10^{-10}	Killed by meteorite in any given year.c

[a] SEER, op. cit.

[b] Richard Wilson, Harvard University, personal communication, February 12, 1986.

[c] Bulloch, B.C., "The Development of Quantitative Risk Criteria and Their Application to Chemical Process Hazard Analysis," ICI Limited, Cheshire, England, 1986.

TABLE V

Aggregate Coverage Levels[a]

Likelihood Level[b]	Transport Configuration		Coverage Level (millions of 1987 $)		
	Route	Vehicle	Corrective Action (CA)	Third-Party Compensation (TPC)	CA & TPC Combined
8	1	Small Truck	0.6	0.6	1.0
8	1	Large Truck	1.4	0.6	1.8
8	1	Railcar	3.4	0.4	3.7
8	2	Small Truck	0.8	0.7	1.0
8	2	Large Truck	1.7	0.7	1.9
8	2	Railcar	3.4	0.4	3.7
7.6	1	Small Truck	1.4	0.7	1.5
7.6	1	Large Truck	3.3	0.8	3.2
7.6	1	Railcar	3.4	0.4	3.7
7.6	2	Small Truck	2.5	0.7	2.6
7.6	2	Large Truck	4.9	0.8	5.2
7.6	2	Railcar	3.4	0.4	3.7
7.3	1	Small Truck	6.9	0.7	7.3
7.3	1	Large Truck	10.0	0.8	10.0
7.3	1	Railcar	3.4	0.8	4.6
7.3	2	Small Truck	7.7	0.8	7.7
7.3	2	Large Truck	11.0	1.2	13.0
7.3	2	Railcar	4.4	0.8	4.7
7	1	Small Truck	14.0	1.2	15.0
7	1	Large Truck	24.0	1.4	25.0
7	1	Railcar	7.8	0.8	8.0
7	2	Small Truck	14.0	1.2	15.0
7	2	Large Truck	24.0	1.4	25.0
7	2	Railcar	7.9	0.8	8.1

[a] Aggregate coverage level per year per vehicle.

[b] Likelihood of 8 = probability of 0.01 per year per vehicle (i.e., expected exceedance every 100 years). Likelihood of 7.6 = probability of 0.004 per year per vehicle (i.e., expected exceedance every 250 years). Likelihood of 7.3 = probability of 0.002 per year per vehicle (i.e., expected exceedance every 500 years). Likelihood of 7 = probability of 0.001 per year per vehicle (i.e., expected exceedance every 1,000 years).

(3) Regardless of the likelihood of exceedance level specified, coverage levels vary considerably from one vehicle category to another.

(4) Coverage levels increase by a factor of approximately 14 for trucks and two for railcars when an acceptable likelihood of 7 rather than 8 is used.

(5) Separate coverage levels for corrective action and third-party compensation add up to more than the coverage level for the combined liabilities.

Other conclusions are presented best by example. For small trucks using either of the generic routes, there is a one in 100 chance (i.e., a likelihood of 8) that events occurring in a given year will result in total costs exceeding $1 million. Therefore, the $1 million in liability coverage currently required by New York State for small trucks corresponds to an estimated probability of 99 percent that all occurrences in a given year will be covered.

As the level of coverage increases, the likelihood that costs would exceed the coverage level decreases. For small trucks, coverage levels of $1.5 million for generic Route 1 and $2.6 million for generic Route 2 have a one in 250 chance per year (i.e., a likelihood of 7.6) of being exceeded by the aggregate costs of events in a given year. Alternatively, these coverage levels are expected to be exceeded once every 250 years. At a coverage level of $15 million (for either generic route), the probability that costs will exceed the coverage level is only one in 1,000 per year (i.e., a likelihood of 7).

Using the results of the risk assessment, it is possible to identify the types of events that would or would not be covered for a given likelihood and coverage level. As discussed above, if coverage levels are set at the one in 100 probability of being exceeded (i.e., a likelihood of 8), the corresponding coverage level would be $1 million for small trucks using either generic route. BIPDAM then shows events with costs that would and would not exceed the coverage level chosen. For example, a terminal point accident for small trucks carrying BWR ionized resin is estimated to result in a cost of $300,000; the $1 million in coverage would be sufficient to cover this event. The events that would not be covered by the $1 million amount are in general very unlikely to occur. For example, a large accident in the woodland setting for small trucks carrying non-fuel irradiated components would cost an estimated $84 million, far above the coverage level. However, this event has only a one in a million probability of occurring per vehicle per year.

ACKNOWLEDGEMENTS

The authors wish to thank Ann Carey, Alan Karnovitz, Stan Hunter, Mary Catherine Fish, Brian Kelleher, and Joe Bergera from ICF, as well as Bill Varcasio, John Zeh, Ed Johnson, Bill Kelleher, and Joseph Jones from NYSDEC, for their expert input to the preparation of this paper. Special thanks go to Margo Brown for her patience and skills while typing this paper.