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STAFF STUDY

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TRANSPORTATION SYSTEMS CENTER
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RISKS OF HAZARDOUS SUBSTANCE SPILLS FROM UNMARKED PACKAGES OR CONTAINERS

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Executive Summary

This study has examined the risk of spills of hazardous substances from transport containers which are unmarked. Three circumstances could lead to incidents where a reportable quantity of a hazardous substance spills from unmarked containers. First, the incident could involve multiple spills from packages too small to require marking. Second, the incident could involve a very large spill of a mixture or solution which was too dilute to require marking. Finally, the transport container could be unmarked because it was not in compliance with Federal Regulations. The study findings in each of these circumstances are summarized below.

Multiple Small-Package Spill Risk

The MTB regulations on the transportation of hazardous substances require packages to be marked with the letters "RQ" when the package contains more than a reportable quantity of a hazardous substance. Packages containing less than a reportable quantity are not considered hazardous substances by MTB. Further, the MTB requires reporting to NRC when a reportable quantity of a hazardous substance spills from a single package or, for bulk shipments, from a single transport vehicle.

These regulations present two categories of risk: first, a carrier could be involved in an incident where many small, unmarked packages spill and because the packages are unmarked the carrier would be unaware of the hazard; second, multiple spills from marked packages could be unreported to NRC because no single package spilled more than an RQ.

Table E.1 shows estimates of the fraction of incidents where an RQ or more spills for these categories of risk. The estimates were derived from the MTB's HMIR data and the probability equation developed in Chapter 3 and the Appendix. The results indicate that less than 0.53 percent of all B hazardous substance spills of an RQ or more are from incidents involving multiple spills from unmarked packages. Further, the comparable fraction is even smaller for A hazardous substances and smaller still for X hazardous substances.

The results are somewhat less complete for incidents spilling more than an RQ which are unreported because no <u>single</u> spill exceeds an RQ. Only two-spill incidents are included in the analysis, but the risk calculations indicate that such cases comprise less than three percent (3%) of all incidents where an RQ or more spills of B hazardous substances. Further, this fraction is dominated by the spills from marked packages, and since only the letters "RQ" are marked on the package, it seems likely that these spills would be reported (over reported) even though reporting is not required by current regulations. They

Table E.1 Summary of Multiple Spill Risks

Description of Incident	Fraction of RQ Spills of X Substances	Fraction of RQ Spills of A Substances	Fraction of RQ Spills of B Substances
1. Unmarked and Unreported Involving multiple* spills from unmarked packages.	$2.7x10^{-5}$	$7.5x10^{-4}$	$5.3x10^{-3}$
2. Unreported A. Involving one unmarked package spill and one spill of less than an RQ from a marked package.	$2.4x10^{-6}$	$5.4x10^{-4}$	$3.6x10^{-3}$
B. Involving two spills of less than an RQ from marked packages	$2.7x10^{-3}$	$1.8x10^{-2}$	$2.1x10^{-2}$

*Includes 2,3 and 4 spill incidents

would be reported because the marking does not indicate the category of hazardous substance or the RQ threshold, so, as long as the package spilled more than one pound, it could potentially be a reportable quantity.

If the regulations were changed to require marking the hazardous substance category as well as RQ ("RQ-X," "RQ-A"...), the over-reporting of small spills could be avoided, but three percent (3%) of all reportable quantity spills of B hazardous substances would not be reported (the multiple, small spills involving marked packages.)

These results are based on several assumptions. Because the probabilities were estimated from hazardous material spill data, the most important assumption is that hazardous substances are shipped and spill in ways which are the same as hazardous materials. An analysis of the spill data for 42 of the 92 Clean Water Act X,A or B hazardous substances supports the validity of this assumption. Other assumptions involve the independence of probability factors across substances and the degree to which the HMIR data is representative of all hazardous material spills.

Large Dilute Spill Risk

MTB regulations define hazardous substances to be above a RQ÷50,000lb. concentration. Shipments at concentrations below this threshold are not subject to regulation, however very large spills could release an RQ of a hazardous substance.

Neither the U.S. Coast Guard's Pollution Incident Reporting System (PIRS) nor the MTB's HMIR contains information on the concentration of the hazardous materials spilled. However, economic considerations probably make shipping dilute concentrations of hazardous substances unattractive. Because shipping costs rise with the weight shipped, only when the substance can be used in the diluted form and where concentration costs exceed the added shipping costs is it economical to ship dilute concentrations of hazardous substances. Two categories of materials meet these conditions: 1) Wastes which can be disposed of in any concentration and are shipped short distances; and 2) Additives to materials which are not hazardous substances, like tetraethyl lead in gasoline*. Both of these categories of materials could be frequently shipped in dilute concentrations.

In addition to being shipped in dilute form, at least 50,000 pounds of the unmarked solution must be released for an RQ to spill. The HMIR data indicates that 0.8 percent of truck incidents and 4.9 percent of rail incidents involved spills of more than 50,000 pounds. The PIRS data indicates that 4.7 percent of the hazardous spills, excluding oil, exceeded 50,000 pounds. The

* Tetraethyl lead is a hazardous substance while gasoline is not a hazardous <u>substance</u> but it is a hazardous <u>material</u>.

large spills in PIRS are mostly from non-transportation sources, however. These percentages represent very loose upper bounds on the fraction of spills which are RQ or more from dilute unmarked packages. This upper bound is based on the very conservative assumption that the concentrations of <u>all shipments</u> are just below the marking threshold, RQ÷50,000. Certainly many specific substances, particularly those in wastes and those used as additivies, could have a higher percentage of spills where an RQ spills from dilute unmarked shipments but in the aggregate these percentages represent loose upper bounds.

Non-Compliance

The very limited available information on non-compliance rates in hazardous materials transportation indicate that non-compliance is common. The study of hazardous material trucking in Virginia* indicated that 10-20% of the trucks did not have proper shipping papers, and 30-40% were not properly placarded. These rates dwarf the fractions of RQ spills from multiple packages and from large dilute shipments.

*Price, Schmidt and Kates "Multi-Modal Hazardous Material Transportation in Virginia" Sept. 1981.

Though the reasons for non-compliance are even sketchier than the non-compliance data, the cost of compliance seems to be an important general reason. Table E.2 shows the important activities required by hazardous material regulation in transportation and an assessment of their contribution to the cost of compliance.

Table E.2 also shows how designating new hazardous substances under CERCLA might affect the cost of compliance to shippers and carriers. The two categories of hazardous substances which were already regulated as hazardous materials will experience very minor increases in the cost of compliance. Newly designated hazardous substances which were not previously regulated (ORM-E), can have a significant impact on the cost of compliance for shippers and carriers which did not previously handle hazardous materials because these shippers and carriers must now become familiar with the full range of MTB's hazardous material regulations and, though the regulatory burden is modest for ORM-E materials, no hazardous material regulations applied before designation.

The assignment of the reportable quantity for a hazardous substance determines the fraction of shipments which are subject to the medium and low incremental costs in Table E.2. However, adjustments to the reportable quantity seem unlikely to affect compliance significantly because training and classification costs can not be avoided, and these costs dominate the incremental costs that vary with shipment volume.

Table E.2 Effect of Designating New Hazardous Substances on the Cost of Compliance

Activity	Impact on Total Cost of Compliance	Incremental Costs by Category of Hazardous Substances (1) (On HM Table)	(2) (Regulated but Not on Table)	(3) (ORM-E)
Training	High	+	+	++
Classification	High	0	-	++
Packaging	High	0	0	0
Marking	Medium	+	+	++
Labeling	Medium	0	0	0
Placarding	Medium	0	0	0
Shipping Papers	Medium	+	+	++
Special Handling	Medium	0	0	0
Spill Reporting	Low	+	+	++

Legend: ++ means significant increase in cost for some shippers or carriers
+ means minor increase in cost
0 means no change or not required
- means minor reduction in cost

On the other hand, adjustments to the RQ of a hazardous substance can affect the number of NRC spill reports dramatically. For example, changing the RQ for calcium hypochlorite from 100 pounds to 1000 pounds could reduce the number of NRC spill reports for that substance by over 20%.

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1.0 Introduction

The purpose of this project is to establish the risks of hazardous substance spills from unmarked packages during transportation. The results of this study will be used by the EPA to aid in establishing reportable quantities for newly designated hazardous substances, to better understand the spill risks and special issues in regulating the transportation of hazardous substances,and if the risks are serious, to suggest adjustments to the existing transportation regulations.

Packages containing hazardous substances might be unmarked for any of three reasons. First, the package might contain less than a reportable quantity* (RQ) of the hazardous substance. Since current regulations require the package to be marked only if it contains an RQ or more, these packages could be unmarked. Second, the package or shipment could contain a mixture or solution of a hazardous substance which is so dilute that it does not require marking. Table 1 shows the concentrations below which packages do not need marking. Third, a package containing a hazardous substance could be unmarked because the shipper is not complying with existing regulations.

*Reportable quantities have been established for five categories of hazardous substances. These categories and the associated RQ's are: 1) X--1 pound; 2) A--10 lbs; 3) B--100 lbs; 4) C--1000 lbs; 5) D--5000 lbs.

TABLE 1: CONCENTRATIONS EXCEEDED BY HAZARDOUS SUBSTANCES

		CONCENTRATION BY WEIGHT	
RQ POUNDS	RQ KILOGRAMS	PERCENT	PPM
5000	2270	10	100,000
1000	454	2	20,000
100	45.4	0.2	2,000
10	4.54	0.02	200
1	0.45	0.002	20

SOURCE: 49 CFR Part 171.8

The risks and issues associated with each of these three situations will be analyzed in this study, but since each situation requires different data and analysis, each will be addressed separately. In the first situation, the study will assess the likelihood that more than an RQ spills from multiple, small, unmarked packages. This risk will be contrasted with the risk of RQ spills from larger, marked packages. The Material Transportation Bureau's (MTB's) Hazardous Material Incident Report (HMIR) data will be used as the primary data for this analysis.

In the second situation, the study will attempt to assess the likelihood that more than an RQ of a hazardous substance spills from shipments which are unmarked because the hazardous substance is so dilute that it does not require marking. Spills of more than 50,000 lbs could release an RQ of a substance without requiring a marking. The HMIR data will be used to estimate the risk of these large spills for rail and truck, and the Coast Guard's Pollution Incident Reporting System (PIRS) will be used to assess the risk for the water modes.

The third situation, non-compliance, involves issues such as the cost of compliance and the relation between RQ levels and compliance rates.

The remainder of this introduction presents some legislative background to this study. Section 2.0 presents a summary of the transportation regulations with respect to hazardous materials and substances. Section 3.0 presents the results of the analysis of the risk of multiple, small package spills. The HMIR data are described, important limitations to the data are identified, and statistics derived from the data are presented. Section 4.0 presents some limited data on the risk of very large spills which are relevant to the risk of RQ spills from unmarked shipments of very dilute mixtures or solutions of hazardous substances. Section 5.0 discusses non-compliance with hazardous materials regulations and examines how designating new hazardous substances might affect the non-compliance rate.

1.1 Legislative Background

Section 311 of the Clean Water Act* (CWA, PL-95-217) establishes a program for regulating hazardous substances. 297 substances were designated as hazardous by EPA pursuant to this legislation. These 297 substances were categorized into five groups and each group was assigned a reportable quantity (RQ). The groups and associated RQs are: 1) X--one pound; 2) A--10 lbs.; 3) B--100 lbs.; 4) C--1000 lbs.; 5) D--5000 lbs.

*The CWA amends the Federal Water Pollution Control Act of 1972 (PL-92-500).

The Materials Transportation Bureau (MTB) of the DOT incorporated these substances into its Hazardous Material Table (49 CFR 172.101). Of the 297 substances, approximately 45% were already on the table by name. An additional 15% were already covered in general categories, not otherwise specified. The remaining 40% were not previously covered. The Hazardous Materials Table has about 360 entries to cover the 297 substances, because many substances have different hazard classes and/or packing requirements depending on the concentration and form.*

MTB has issued rules which require shippers to mark packages which contain an RQ or more of a hazardous substance. The EPA is concerned that significant spills could occur where the transport vehicle operator has no knowledge that a hazardous situation exists because many small, unmarked packages spill. Without knowledge of the hazard no clean-up or notification of NRC (National Response Center) would occur and the public would be left at risk. Assessing the likelihood of this type of spill incident is the objective of Section 3.0 of this report.

*For example, Aldrin has six entries 1) Aldrin, Poison B; 2) Aldrin, cast solid, ORM-A; 3) Aldrin mixture, dry (>65% aldrin), Poison-B; 4)Aldrin mixture dry (≤ 65% aldrin), ORM-A; 5)Aldrin mixture, liquid (>60% aldrin), Poison-B; 6) Aldrin mixture, liquid (≤60% aldrin),ORM-A.

The Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA) (PL-96-10) greatly expands the list of hazardous substances. Section 101 (14) adds to the 297 substances designated by the Clean Water Act,

> "any element, compound, mixture, solution, or substance designated pursuant to section 102 of this Act, (C) any hazardous waste having the characteristics identified under or listed pursuant to section 3001 of the Solid Waste Disposal Act (but not including any waste the regulation which under the Solid Waste Disposal Act has been suspended by Act of Congress), (D) any toxic pollutant listed under section 307(a) of the Federal Water Pollution Control Act, (E) any hazardous air pollutant listed under section 112 of the Clean Air Act, and (F) any imminently hazardous chemical substance or mixture with respect to which the Administrator has taken action pursuant to section 7 of the Toxic Substances Control Act."

These additions bring the total number of hazardous substances to 691*. Of the 691, roughly 607 are chemical substances and the remainder are waste streams. All of the additions are assigned an RQ of one pound until EPA designates a more appropriate RQ. MTB will incorporate these additional substances into the DOT regulations after the RQ levels have been set, though, MTB may make certain modifications to the EPA list.

*This number will change somewhat under the final list to be published in the Proposed Rule.

2.0 Regulation of the Transportation of Hazardous Materials

The Materials Transportation Bureau (MTB) of the Department of Transportation (DOT) issues regulations to assure the safe transportation of hazardous materials (HM). The MTB has incorporated EPA-designated hazardous substances and wastes into DOT's Hazardous Materials Table (a partial list of DOT-regulated hazardous materials) thereby making them subject to DOT HM regulations when shipped in a quantity equal to or greater than the reportable quantity established by the EPA for that substance.

This section will give an overview of the hazardous materials regulations, emphasizing details pertaining to hazardous substances. The first subsection identifies hazardous materials regulatory responsibility within DOT; the second subsection presents requirements for HM transportation covered by these regulations. Subsection 2.3 indicates who is responsible for complying with the requirements, and Subsection 2.4 outlines two mechanisms for relief from HM regulations. The final subsection explains the specific requirements for hazardous substances under the DOT regulations.

2.1 Regulatory Responsibility

Federal regulations prior to 1975 (U.S.C. 831-835) covered only hazardous materials carriers engaged in interstate or foreign commerce and the shippers who used the services of these carriers. The Hazardous Materials Transportation Act of 1975 broadened this scope with the result that all intrastate carriers can be regulated by DOT.* The Department, however, has limited its regulations by excluding intrastate motor carriers except when they transport hazardous wastes** and substances. In the instances when intrastate carriers transport these materials, all regulations pertaining to hazardous substances and wastes must be observed.

Since its creation in 1975, the Materials Transportation Bureau (MTB) has been the lead agency in DOT's hazardous materials safety program. Although MTB co-ordinates rule-making with the modal administrations***, all HM regulations are issued

*Lawrence W. Bierlein, *Red Book on Transportation of Hazardous Materials*, 1977.

**The CFR is ambiguous on this point. 49CFR171.1 excludes intrastate motor carriers from Federal regulation when a state is operating a hazardous waste program under interim authorization in accordance with 40CFR123,F. However, 49CFR171.3(a) requires interstate and intrastate transport of hazardous wastes to be in accordance with Federal regulations. The MTB policy currently requires compliance as stated in 171.3(a).

***The modal administrations are: Federal Railroad Administration (FRA), Federal Highway Administration (FHWA), Federal Aviation Administration (FAA) and the U.S. Coast Guard (USCG).

by the MTB, with the exception of those pertaining to bulk transportation by water which are issued by the U.S. Coast Guard. MTB also regulates manufacturers of hazardous material shipping containers and shipments of hazardous materials which are transported by more than one mode (intermodal). Enforcement authority to assure compliance with the regulations is delegated to the modal administrations, with MTB performing this function for container manufacturers, intermodal shipments and pipeline. Table 2.1 summarizes these hazardous materials responsibilities.

2.2 Scope of Hazardous Materials Regulations Requirements

Hazardous materials regulations cover all aspects of transportation. Responsibility for compliance generally falls to shippers, carriers and/or container manufacturers. The general areas regulated include:

1. Material Identification and Classification
2. Packaging
3. Marking
4. Labeling
5. Placarding
6. Preparing Shipping Papers
7. Accident Reporting
8. Handling (mode-specific requirements)

The following subsections describe these general areas; emphasis is on the requirements for shippers and carriers.

Table 2.1: Hazardous Materials Regulatory Responsibilities in the Department of Transportation

Mode	Rule-Making	Inspection/Enforcement
Rail	MTB/FRA	FRA
Highway	MTB/FHWA	FHWA
Air	MTB/FAA	FAA
Water	USCG	USCG
Pipeline	MTB	MTB
Intermodal	MTB	MTB
Container Manufacturers	MTB	MTB

2.2.1 Material Identification and Classification

Hazardous materials regulations are applicable to all materials found on the Hazardous Materials Table (49 CFR 172.101) as well as to any material with the chemical properties of a DOT hazard class. The HM Table is an alphabetical listing by proper DOT shipping name of materials designated as hazardous by the Department. Hazardous substances designated by the EPA under the Clean Water Act are included in the Table. It is essential for a shipper to determine the proper shipping name of a material, which is not necessarily the brand, trade or chemical name, in order to follow the procedures required for transporting that material. The Table identifies a material's hazard class, the primary determinant of most requirements.

The Table does not list all the specific materials subject to DOT regulation, however. Any material which has the chemical properties of a DOT- specified hazard class is subject to regulation, even though it does not specifically appear on the HM Table.* DOT hazard classes are shown in Table 2.2. Identification and classification of materials not specifically appearing on the HM Table is accomplished through research by the manufacturer (shipper) to see if any hazard class criteria are met. After a material is identified as belonging to a hazard class, all regulations pertaining to that class must be observed.

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*In these cases, the proper shipping name of the material is a hazard class, not otherwise specified (n.o.s). For example, flammable liquid, n.o.s. could be the proper shipping name.

Table 2.2 DOT Hazard Classes

Explosives: Class A, B, C and Blasting Agent (173.53, 173.88, 173.100, 173.114a)

Radioactive Materials (173.389)

Poison A (173.326)

Poison B (173.343)

Flammable Materials: Solid, Liquid, Gas (173.150, 173.115, 173.300)

Nonflammable Compressed Gas (173.300)

Oxidizers (173.151)

Corrosive Materials (173.240)

Irritating Materials (173.381)

Combustible Liquids (173.115)

Etiologic Agents (173.386)

Organic Peroxides (173.151)

Other Regulated Materials (ORM-A, B, C, D, E) (173.500)

Note: Citation for hazard class definition in 49 CFR are listed in parentheses.

It should be noted that DOT's regulatory philosophy differs from that of that EPA. DOT requires that manufacturers share the HM identification function thereby shifting responsibility from the Department to those involved in the transportation of these materials. The EPA, however, designates hazardous substances and wastes and places no responsibility for additional identification outside the agency.

2.2.2. Packaging

DOT specifies construction and quality control requirements for containers used in transporting hazardous materials (see 49 CFR Parts 178 and 179 for specifications). Packaging for a hazardous material can be selected only after the proper shipping name and hazard class have been determined. The HM Table refers to the section of Title 49 CFR where packaging requirements for a particular material are listed. Requirements are outlined by hazard class or, in some cases, by individual commodity. The regulations covering packaging are very specific and permit little or no discretion by the shipper.

Materials for which no packaging requirements are specified (usually small quantities) must, nevertheless, satisfy minimal requirements by being securely packaged in strong, tight packages (see 49 CFR 173.24, "Standard Requirements for All Packages"). It should be noted that ORM-E materials, all of which are hazardous substances, have no packaging requirements and therefore are subject only to the minimal requirements.

2.2.3 Marking

DOT regulations require that certain information be placed on each package, portable tank, cargo tank, and tank car. Marking may be printed on the surface of the container or on a label, tag or sign. Marking usually includes:

1. The proper shipping name of the contents of the container. (From the Hazardous Materials Table)
2. Letters and numerals identifying the specification packaging being used.
3. The letters "RQ" on hazardous substance shipments (after July 1, 1983).
4. The name and address of the consignor or consignee unless the shipment does not require transfer from one carrier to another.
5. Additional warnings e.g. "This End Up," and other markings pertaining to a specific hazard classes, e.g. radioactive material packages exceeding 110 lbs. must have the weight marked; some packaging of flammable liquids must have the flash point noted.

2.2.4 Labeling

The hazardous material label is a colored 4"x4" square-on-point (diamond) warning of the hazard of the material being shipped. It must be printed on or affixed to the package near the marked proper shipping name. Labels differ by hazard class; the color and design of each is described in the HM regulations. More than one label may be required if a material meets the definition of more than one hazard class.

2.2.5 Placarding

The placard, like the label, is a colored warning signal of the hazard class of the material. The square-on-point placard measures 10 3/4" on each side and must be affixed to the outside of the transport vehicle.

A placard is required if a transport vehicle contains 1,000 pounds or more of one hazard class. However, a vehicle containing 1,000 pounds or more of each of two or more hazard classes can be placarded "Dangerous" in place of the separate placards specified for each of the classes. If, however, 5,000 pounds or more of a class is loaded at one facility, the placard for that class must be affixed. Therefore, a transport vehicle may have more than one placard.

2.2.6 Shipping Papers

All shipments of hazardous materials must be accompanied by shipping papers. The exceptions are ORM-A, B, and C materials which require shipping papers only if transported by air or water and ORM-D materials which require them only for air shipments (unless the material is a hazardous substance or hazardous waste in which case HM shipping papers are <u>always</u> required). If other non-hazardous commodities appear on the same shipping paper, hazardous materials must be entered first or highlighted in a color contrasting with the non-hazardous section or designated by an "X" in the column captioned "HM." The letters "RQ" can replace the "X" if the material is a hazardous substance. The HM shipping paper must also include:

1. The proper shipping name of the material
2. The hazard class
3. The material's identification number (taken from the HM Table)
4. The total quantity being shipped
5. Notation if the shipment is being made under a Limited Quantity Exception (see Sec. 2.4.1)
6. Notation if the shipment is being made under an exemption (see Section 2.4.2)
7. The letters "RQ" if the material is a hazardous substance, entered before or after the basic description.
8. Additional information which is required for transportation by a specific mode, e.g. the name of the shipper must be included if the shipment is by water.
9. Certification by the shipper that the material being tendered is in compliance with DOT's regulations.

The following are examples of shipping paper entries which include (1) varying levels of specificity of proper shipping name, (2) a hazardous substance, (3) a limited quantity shipment.

1. Nitrogen, Non-flammable gas, UN1066, 800 pounds
   Cement, liquid n.o.s., Flammable liquid, NA1133, 25 pounds
   Flammable liquids, n.o.s., UN1993, 100 pounds
2. RQ, Cresol, Corrosive material, NA2076, 1500 pounds
3. Methyl acetate, Flammable liquid, Ltd. qty., UN1231, 10 gallons

2.2.7 Accident Reporting

A carrier is required to report to the MTB, in writing, any unintentional release of a hazardous material within fifteen days of the date of the discovery. If the results of the release are particularly severe, i.e. a death, hopitalizing injury and/or $50,000 or more in damages occurs, the incident must be reported by telephone as soon as possible. Currently, regulations (see 49 CFR 171.17) state that a release of a hazardous substance into or upon navigable waters or adjoining shorelines, in a reportable quantity from <u>one package</u> or from one transport vehicle if not packaged, must be reported to the U.S. Coast Guard National Response Center (NRC) as well as to MTB. Due to the CERCLA legislation, hazardous substance releases in the future will be required to be reported to the National Response Center regardless of the medium into which they are spilled, and DOT/MTB regulations will have to be revised to reflect the "all media" scope of hazardous substance releases under CERCLA.

2.2.8 Mode-Specific Requirements

Regulations pertaining to the transportation of hazardous materials by specific modes are found in 49 CFR, Parts 174 (rail), 175 (air), 176 (water) and 177 (motor vehicle). In these

Parts, general hazardous materials operating, inspection, handling, and loading requirements are specified along with detailed requirements by hazard class. These regulations are in addition to those explained in subsections 2.2.1-2.2.7 above and are aimed at assuring safety in specific modal operating environments.

2.3 Compliance Responsibility

As indicated in Section 2.2, the shipper or the carrier is responsible for compliance with hazardous materials regulations. In some cases, the shipper has the primary responsibility for compliance and the carrier is required to check the compliance of shipments tendered to him. Table 2.3 indicates the parties responsible for compliance with the areas of HM regulations outlined in sections 2.2.1-2.2.8 above.

2.4 Relief from Hazardous Materials Regulations

Partial relief from HM regulations can be granted through: (1) a limited quantity exception or (2) an exemption. This section will explain the differences between these two mechanisms and the degree of regulatory relief granted under each.

Table 2.3: Compliance Responsibilities

Regulatory Areas	Shipper	Carrier	Carrier Check
	Responsible Party		
Material Identification and Classification	x		
Packaging	x		x
Marking	x		x
Labeling	x		x
Placarding	x	x	
Shipping papers	x		x
Mode-Specific Requirements		x	
Accident Reporting		x	

2.4.1 Limited Quantity Exceptions

Limited quantity exceptions grant partial relief from hazardous materials regulations to shippers and carriers based, generally, upon hazard class and maximum quantities shipped in inside packages. The principal relief is from packaging requirements although for most hazard classes concommitant relief from labeling, placarding and mode-specific requirements is also granted. Shipping paper and marking requirements, however, are never excepted. Some specific commodities (as indicated on the HM Table) as well as entire hazard classes, are excluded from relief through a limited quantity exception.

Under some limited quantity exceptions, a maximum quantity is specified for each individual inside package as well as for each outside package. In other cases, only the individual inside packages have maximum quantity limitations. Table 2.4 indicates by hazard class the requirements from which a shipper or carrier can be excepted if quantity limitations are met. The table presents four subsets of hazard classes: Subset A has eligibility criteria based only on the quantities in individual inside packages. Subset B has eligibility limits on both the inside and outside quantities. The hazard classes in Subset C are not eligible for limited quantity exceptions and those in subset D have no limited quantity exceptions because specification packaging, labeling, placarding and mode-specific procedures are not required.

Table 2.4: Limited Quantity Exceptions

	Spec. Pkg.	Label	Placard	Modal Requirements
A. Inside max. qnty. spec. Outside quantity not spec.				
- Flam. Liq., Corr. Liq., Compressed Gas	Y	Y	Y	Y
- Poison B, Liquid	Y	N	Y	Y
- Combustible Liquid	Y	Y	N	Y
- ORM-A, -B, -C	Y	NOT REQUIRED		
B. Inside and Outside max. quantities specified				
- Oxidizers, Organ. Perox., Flam. Solid, Corr. Sol., Radioactive	Y	Y	Y	Y
- Poison B, solid	Y	N	Y	Y
C. No limited Qty. Exceptions Allowed				
- Explosives, Poison A, Irritating Materials, Etiologic Agents				
D. No limited Qty. Exceptions Necessary				
- ORM-D, -E		NOT REQUIRED		

Y = Exception allowed
N = No exception

Note: Shipping Papers and Marking are always required.

2.4.2 Exemptions

Exemptions from HM regulations are special permits issued to individuals granting relief from a specific hazardous materials regulation. Exemptions differ from limited quantity exceptions in that they are offered not to everyone shipping HM in an approved manner but only to the person who has applied for and been granted the exemption (See Table 2.5 for a full comparison of the two relief mechanisms).* Although any person subject to a HM regulation can apply for an exemption from that regulation, most exemptions pertain to relief from DOT packaging requirements. The burden falls on the applicant to show that the level of safety for the HM transported under the exemption is equal to or exceeds the level of safety achieved through the customary requirements.

2.4.3 Summary of Relief Mechanisms

Table 2.5 summarizes the major points concerning limited quantity exceptions and exemptions. For hazardous materials and substances transported under an exemption, the level of safety is at least equal to that required by the regulations (as shown by the applicant for the exemption). With limited quantity

* Any person who wishes to take advantage of an exemption granted to another party or become party to the application may apply to do so.

Table 2.5: Summary of Limited Quantity Exceptions and Exemptions

Limited Quantity Exceptions	Exemptions
1. Automatically granted to shippers of eligible commodities if package size limitations are met. No application process required.	1. Applied for by, and granted to, individuals seeking relief from a regulation, usually the specification packaging requirement.
2. Although primary relief is from specification packaging requirements, relief from other regulations is generally granted concommitantly.	2. Relief only from the the regulatory requirement applied for.
3. No time limitation on exception. Granted at any time that eligibility criteria met.	3. Exemption expires two years from date of issuance, although renewals may be granted.
4. Underlying assumption that risk for eligible materials is reduced in small package shipments.	4. Burden on applicant to show that a required level of safety can be achieved under the exemption.

exceptions, small packages are relieved from packaging requirements, with concommitant relief from other requirements usually granted. The underlying assumption is that the risk of transporting eligible materials in small quantities is reduced sufficiently to warrant relief from some regulations.

Only hazardous substances which are not in ORM hazard classes are affected to any extent by limited quantity exceptions. These materials are usually eligible for the full relief granted to their respective hazard classes if package size limitations are met. ORM-D and E materials are not subject to packaging, labeling, placarding, and modal requirements; therefore, an exception would be meaningless. ORM-A, B and C materials can be relieved only from packaging requirements because for these material, like ORM-D and E materials, labeling, placarding and modal requirements do not apply.

2.5 Hazardous Substances under DOT Regulation

The incorporation of EPA-designated hazardous substances into the DOT's Hazardous Material Table begins with the identification of the common forms and critical concentrations of each material and their categorization by DOT hazard classes. Those hazardous substances not exhibiting characteristics of any other hazard class are designated as ORM-E. Table 2.6 illustrates this procedure using the 297 Clean Water Act hazardous substances. As noted in Table 2.6, 45% of these hazardous substances were

Table 2.6: How Are Newly Designated Hazardous Substances Incorporated into the Regulations

1. Identify the common forms and critical concentrations of each substance.

   a. For example: Aldrin has six entries: 1) Aldrin; 2) Aldrin, cast solid; 3) Aldrin mixture dry (>65%); 4) Aldrin mixture dry (<65%); 5) Aldrin mixture liquid (> 60%); 6) Aldrin mixture liquid (<60%).

2. Classify each hazardous substance into the appropriate hazard class. Of the 297 CWA hazardous substances:

   a. 45% were already on the HM Table
   b. 15% were previously regulated but not on the HM Table
   c. 40% were not previously regulated and assigned ORM-E.

materials already listed on the HM Table and 40% were designated as ORM-E because they did not exhibit characteristics of other hazard classes. The remaining 15% were not specifically listed on the HM Table, but were previously regulated as a result of the manufacturer's (shipper's) responsibility for identifying materials which exhibit characteristics of established hazard classes. With their incorporation into DOT's Hazardous Materials Table, hazardous substances become subject to the hazardous material regulations described in Section 2.2 above.

Table 2.7 summarizes the DOT requirements for hazardous substances in transportation. As the table indicates, hazardous substances in DOT hazard classes other than ORM- A,B,C,D and E are subject to full regulatory burden whereas the ORM classes are relieved from many of the requirements. The following observations on the regulation and designation of hazardous substances should be noted:

1. For hazardous substances already listed on DOT's Hazardous Materials Table, designation increases regulation by requiring:

    a. The letters "RQ" on shipping papers
    b. The letters "RQ" marked on packages
    c. Spill reporting to the National Response Center (NRC)

Table 2.7: Regulatory Requirements for Hazardous Substances

Requirement	ORM-E	Hazard Class ORM-A,B,C	ORM-D	All Others
Identification & Classification*	N	N	N	N
Packaging	N	Y	N	Y
Marking	Y	Y	Y	Y
Labeling	N	N	N	Y
Placarding	N	N	N	Y
Shipping Papers	Y	Y	Y	Y
Accident Reporting	Y	Y	Y	Y
Modal Requirements	N	N	N	Y

N = Not Required
Y = Required

*For hazardous substances, EPA designates the material and DOT classifies it.

2. For hazardous substances not on the Table but previously regulated, designation will increase regulation as in 1 (above) but will simplify classification by the addition of the materials to the HM Table.

3. For hazardous substances not previously regulated (ORM-E), designation increases regulation by requiring:
   a. Identification of the substance
   b. HM shipping papers with the letters "RQ" marked
   c. Minimal packaging requirements
   d. HM marking including the letters "RQ"
   e. Accident reporting to NRC and MTB.

   ORM-E materials have no packaging, labeling, placarding or mode-specific requirements.

4. Regulations require that only the letters "RQ" be marked on the shipping papers and packages containing a reportable quantity. Therefore, a carrier spilling a hazardous substance has no information as to whether a reportable quantity has spilled even if the size of the spill can be determined (unless the entire package spills). Therefore, it is likely that a carrier will report all spills from packages marked "RQ" to NRC because reporting is easy and reporting all spills from marked packages quarantees compliance with the regulations. Replacing the letters "RQ"

with "RQ-X", "RQ-A", "RQ-B," "RQ-C," or "RQ-D" would convey the reportable quantity threshold to the carrier and, therefore, elicit the intended reporting response.

5. Since spills must be reported to NRC only when an RQ spills from a single package, there may be incidents in which an RQ spills from many <u>marked</u> packages which do not require reporting because no individual package spilled more than an RQ.

3.0 Multi Package Spill Risk

This chapter assesses the risk of reportable quantity (RQ) spills in incidents involving multiple spills from unmarked packages. The Materials Transportation Bureau's (MTB's) Hazardous Material Incident Report (HMIR) data is used in the analysis. Table 3.1 presents a brief description of the information contained in each spill report. The items used in this analysis are marked with an asterisk.

The following section presents a review of the limitations of the HMIR data. This is followed by a general summary of the spill data. The third section presents the multi-package spill risk assessment. Finally, the fourth section presents the conclusions.

3.1 Limitations to the HMIR Data

The information contained in this sub-section is taken from four reports on HMIR data:

1) Programs for Ensuring the Safe Transportation of Hazardous Materials Need Improving by the Comptroller General of the U.S., 1980.

TABLE 3.1 - INFORMATION ON A HMIR RECORD

NUMBER	ATTRIBUTE NAME	ABBREV	TYPE	LENGTH	KEYED
* 1	REPORT_NUMBER	RPTNO	TEXT	8	YES
* 2	MULTIPLE_CODE	MTPL	TEXT	1	YES
* 3	MODE	MODE	TEXT	1	YES
* 4	DATE_OF_INCIDENT	IDATE	DATE	6	YES
5	TIME_OF_INCIDENT	ITIME	TEXT	4	
* 6	INCIDENT_CITY	ICITY	TEXT	13	
* 7	INCIDENT_STATE	IST	TEXT	2	YES
* 8	CARRIERS_DUNS	CDUN	TEXT	9	YES
9	SHIPPERS_DUNS	SDUN	TEXT	9	YES
10	ORIGIN_CITY	OCITY	TEXT	13	
11	ORIGIN_STATE	OST	TEXT	2	YES
12	DESTINATION_CITY	DCITY	TEXT	13	
13	DESTINATION_STATE	DST	TEXT	2	YES
14	INJURIES	INJUR	INTEG	4	YES
15	DEATHS	DEAD	INTEG	3	YES
16	DAMAGES	DAMAG	INTEG	8	YES
17	DAMAGE_CODE	DAMCD	TEXT	1	YES
* 18	QUANTITY_RELEASED	RQUAN	INTEG	7	
* 19	UNITS_OF_QUANT_RELEASED	RUNIT	TEXT	3	
* 20	COMMODITY_CODE	CMCD	TEXT	5	YES
21	COMMODITY_CLASS	CMCL	TEXT	2	YES
* 22	CONTAINER_1	CONT1	TEXT	8	YES
* 23	FAILURE_CODE_1_CONT_1	FC1C1	INTEG	2	YES
* 24	FAILURE_CODE_2_CONT_1	FC2C1	INTEG	2	YES
* 25	CAPACITY_CONTAINER_1	CAP1	INTEG	6	
* 26	CAPACITY_UNITS_CONT_1	UNIT1	TEXT	3	
* 27	NUMBER_IN_SHIPMT_CONT_1S	NSH1	INTEG	5	
28	NUMBER_FAILED_CONT_1S	NFL1	INTEG	5	
29	GAUGE_OF_CONTAINER_1	GAUG1	TEXT	6	
30	MANUFACTURERS_DUNS_1	MDUN1	TEXT	9	YES
31	CONTAINER_2_CODE	C2C	TEXT	1	
32	TANK_CAR_ID_NO	TCID	TEXT	10	
33	REGISTRATION_EXEMPTION_NO	REGEX	TEXT	6	YES
34	INSPECTION_DATE	INSP	DATE	6	
35	LABEL_OR_PLACARD	LRP	TEXT	7	
36	COMPLETENESS_CODE	COMPL	TEXT	1	
37	SIGNIFICANCE_OF_REPORT	SIGNF	TEXT	1	
38	GENERAL_CAUSE_OF_INCIDENT	CAUSE	TEXT	1	YES
39	RESULT_OF_RELEASE	RSLT	TEXT	1	YES
40	RECOMMENDATION_ON_REPORT	RECOM	TEXT	1	
41	APPARENT_VIOLATION	VIOL	TEXT	1	
42	MISCELLANEOUS_INFORMATION	MISC	TEXT	2	YES
43	CARRIERS_NAME	CARRI	TEXT	30	
44	SHIPPERS_NAME	SHIPR	TEXT	30	
45	COMMODITY_NAME	COMOD	TEXT	19	
46	CONTROL_NUMBER	CONO	INTEG	8	YES
47	DATE_ADDED_TO_DATA_BASE	DOE	DATE	6	YES
48	DATE_OF_LAST_CHANGE	DOC	DATE	6	YES

2) "A Comparison of FRA and MTB Reports Regarding Hazardous Materials Spills in 1976" by Theodore S. Glickman, December, 1978. TSC Report No. SS-223-U5-35.

3) "Analysis of Hazardous Chemical Spills Along the Coasts and Major Waterways of the United States" by Paul Fong, Juan Bellantoni and Jeffrey Garlitz, March, 1981. TSC Report No. CG-123-1.

4) "An Analysis of the Underreporting of Hazardous Material Incidents/Accidents as Filed on DOT F 5800.1" by Lillie Ward, September, 1980. TSC Report No. SS-223-U6-124.

The first report, the GAO report, identified three limitations which are significant for this study. 1) Only interstate carriers report to HMIR. Intrastate carriers are not required to report. 2) Most incidents which occur in loading, unloading and storage are probably not reported to MTB because shippers and freight forwarders are not required to report. 3) 1,272 highway carriers have reported spill incidents to HMIR since 1971. This is only 11% of the highway carriers known to carry hazardous materials and all hazardous material carriers are not known. These three points suggest substantial underreporting of highway hazardous material spill incidents, though they give no indication of the size of this problem.

The second report, the rail report, compares the Rail Accident/Incident Reporting System (RAIRS) data with HMIR data. It reports that in 1976, only 60% of the reports in RAIRS were also in HMIR. Further, 20% of the HMIR data involving rail and damages of more than $5K were not in RAIRS.* These findings suggest substantial underreporting of rail hazardous material spills. Because RAIRS involves spills where damages exceed $2300, the size of the HMIR underreporting problem for small shipments is unknown though HMIR data probably has at least 60% fewer incidents than it should.

The third report, the water report, compares the U.S. Coast Guard's Pollution Incident Reporting System (PIRS) data with HMIR data. As expected, there is very little overlap: less than 0.5% of the water spills in one data base are found in the other. The other pertinent items found in this report relate to the data quality in HMIR: Spill size is reported regularly only after 1976; the use of the multiple spill report code is unreliable; and many keypunch errors plague the data.

The fourth report, the underreporting study, uses a Zipfian analysis** to suggest the total extent of underreporting in the

* RAIRS has a lower damage threshold for reporting of $2300, while all hazardous material spills should be reported in HMIR.

** Zipf explored the relationship between rank and city size, for example, and found Rank (R) X Size (S) = Constant (C). More generally, the relationship is expressed $RS^p = C$. Damage replaces size in this study of hazmat spills.

HMIR data. The analysis suggests that the underreporting is very substantial and that small damage incidents (less than $100) should account for 99% of the incidents rather than the 85% found in HMIR data.

These four reports suggest that there are serious problems with the HMIR data. The most serious is the underreporting of small damage highway spill incidents. The very substantial underreporting in this area should be kept in mind as the results presented in the next sections are read.

3.2 Statistics from HMIR Data Analyis

This section presents a general summary of HMIR data. Before presenting the statistics, some definitions are necessary. There is a HMIR record for each outside package from which a hazardous material spilled. Because outside packages are marked, this record-outside package correspondence works well in the data analysis.

Multiple package spill incidents have been defined, in this analysis, as groups of records for which the date, incident location (city and state), and carrier are the same. While this is the best definition which the data permits, two types of errors are obviously possible. First, vehicles of a given carrier could be involved in more than one incident in a given city on a single day, but the definition will create a single multiple spill incident. Second, vehicles of two carriers could be involved in an accident and each could spill hazardous materials. This multiple spill incident would be treated as two single spill incidents with the above definition. Circumstances leading to these errors are judged relatively unlikely however, so the results obtained by using the above definition should be dependable.

The 92 X, A, B hazardous substances designated pursuant to Section 311 of the Clean Water Act are those treated in detail in this study. Of these 92 substances, 49 have specific, unique, commodity codes in the HMIR coding system. These 49 substances are presented in Table 3.2 along with their codes. The remaining 43 X, A, B hazardous substances are assigned HMIR commodity codes for broad, hazard class, "not-otherwise-specified" (N.O.S.) categories. Table 3.3 shows the distribution of hazard class for these 43 substances. Because the hazard class codes relate to many materials which are not hazardous substances, data under these broad codes will not be included with that for the 49 substances for which there are unique commodity codes. Therefore, the data presented below on hazardous substances relates only to the 49 substances in Table 3.2. Forty-two of these 49 substances were on the Hazardous Material Table prior to the inclusion of hazardous substances on November 20, 1980, so they provide a longer spill history than new additions.*

* Only one incident was found for the 7 substances included after November 20, 1980.

TABLE 3.2 - X,A,B HAZARDOUS SUBSTANCES EXPLICITLY IDENTIFIED IN THE HMIR DATA

Hazardous Substance, DOT Hazard Class	Category	HMIR Code
Acetone Cyanhydrin, Poison B	A	01020
Acrolein, Flammable Liquid	X	01130
Acrylonitrite, Flammable Liquid	B	01140
Allyl Alcohol, Flammable Liquid	B	01200
Aldrin, Poison B	X	01210,01214
Aldrin Mixtures, Poison B or ORM-A	X	01220,01230 01233,01236
Ammonia Anhydrous, Non-Flammable Gas	B	01620
Barium Cyanide, Poison B	A	01980
Benzyl Chloride, Corrosive	B	02150
Calcium Cyanide, Poison B	A	3800
Calcium Hypochlorite, Hypochlorite Solution, Oxidizer	B	02560,05868,05870
Carbonryl (Phosgene), Poison A	B	02662
Chlordane, Flam Liq/Combustable Liquid	X	03135
Chlorine, Nonflammable Gas	A	03140
Chlorobenzol (Chlorobenzene), Flammable Liquid	B	03169
Copper Acetoarsenite, Poison B	B	03690
Copper Chloride, ORM-B	A	03705
Crotonaldehyde, Flammable Liquid	B	03750
*Cupric Acetate, ORM-E	B	03781
*Cupric Nitrate, Oxidizer	B	03782
*Cupric Oxalate, ORM-E	B	03783
*Cupric Sulfate, ORM-E	A	03784
*Cupric Sulfate, ammoniated, ORM-E	B	03785
*Cupric Tartrate, ORM-E	B	03786
DDT, ORM-A	X	03980
Dichlorobenzene, liquid, solid ORM-A	B	04057,04058
Dichlorophenoxyacetic acid (2,4D acid), ORM-A	B	04122
Dieldrin, ORM-A	X	04156
Hydrogen, Sulfide Flammable Gas	B	05860
Hydrogen Cyanide (Hydrocyanic acid), Poison A	A	05730,05740,05760
Lindane, ORM-A	X	06275
Malathion, ORM-A	A	06514
Mercuric Cyanide, Poison B	X	06620
Mercuric Sulfate, Poison B	A	06730
Mercurous Nitrate, Oxidizer	A	06790
Methyl Mercaptan, Flammable Gas	B	07090
Methyl Parathion, Poison B	B	07110,07120,07130 07131
Parathion, Poison B	X	08100,08110,08120,08130
Phosphorous White or Yellow, Flammable Solid	X	08450,08460
Phosphorous Pentasulfide, Flammable Solid	B	08415
* Polychlorinated Biphenyls, ORM-E	A	08575
Potassium Cyanide, Poison B	A	03830,03840
Potassium Permanganate, Oxidizer	B	08250
Silver Nitrate, Oxidizer	X	09340
Sodium Cyanide, Poison B	A	03850,03860
Sodium Nitrite, Oxidizer	B	09640,09650,09660
Strychnine, Poison B	A	09872
Tetraethy Lead, Motor fuel anti-knock, Poison B	B	10130,07480
Tetraethyl Pyrophosphate, Poison A or B	B	10140,10150,10160 10170
Zinc Cyanide, Poison B	A	10950

*Hazardous substances added after November 20, 1980.

TABLE 3.3. DISTRIBUTION OF HAZARD CLASS FOR THE 43 SUBSTANCES ASSIGNED TO THE "N.O.S" GROUPS

Hazardous Substance	Category	Class
n-Butyl Phthalate	B	ORM-E-
Cadmium Acetate	B	ORM-E-
Cadmium Bromide	B	ORM-E-
Cadmium Chloride	B	ORM-E-
Captan	A	ORM-E-
Carbofuran	A	Poison-B-
Chlorphrifos	X	ORM-A-
Coumaphos	A	Poison-B-
Cyanogen Chloride	A	Poison-A-
2,4-D esters	B	ORM-E-
Diazinon	X	ORM-A-
Dichlone	X	ORM-E-
Dichlorvos	A	Poison-B-
Disulfotan	X	Poison-B-
Diuron	B	ORM-E-
Endosulfan	X	Poison-B-
Endrin	X	Poison-B-
Ethian	A	Poison-B-
Ferric Fluoride	B	ORM-E-
Ferrous Chloride	B	ORM-B, Corrosive
Guthion	X	Poison-B-
Heptachlor	X	ORM-E-
Hexachlorocyclo pentadiene	X	Corrosive-
Kepone	X	ORM-E-
Mercaptodimethur	B	ORM-E-
Mercuric nitrate	A	Oxidizer-
Mercuric thiocyanate	A	Poison-B-
Methoxychlor	X	ORM-E-
Mevinphos	X	Poison-B-
Naled	A	ORM-E-
Naphthenic aicd	B	ORM-E-
Pentachlorophenol	A	ORM-E-
Propargite	A	ORM-E-
Sodium Hypochlorite	B	Corrosive, ORM-B-
2,4,5-T acid	B	ORM-A-
2,4,5-T amines	B	ORM-E-
2,4,5-T esters	B	ORM-E-
2,4,5-T salts	B	ORM-E-
2,4,5-TP acid	B	ORM-A-
2,4,5-TP acid esters	B	ORM-E-
TDE	X	ORM-A-
Toxaphene	X	ORM-A-
Trichlorophenol	A	ORM-A-

Summary:

21	ORM-E
10	Poison B
7	ORM-A
3	Corrosive
1	Poison A
1	Oxidizer
43	Total

Table 3.4 presents some summary statistics derived from the HMIR data between 1976 and roughly August, 1981. Approximately 14% of the records are involved in multiple spill incidents though only 7% of the incidents involve multiple spills. The 49 X, A, B hazardous substances were involved in only 1.8 percent of the spill reports and only 1.4 percent of the multiple spill reports. Furthermore, only 11% of the hazardous substance reports were involved in multiple spill incidents.

Item 4 in Table 3.4 shows that the modal distribution of incidents is roughly the same for multiple spill incidents as it is for all incidents. Item 5 shows that vehicular accidents and damage by other freight are somewhat more likely in multiple spill incidents and that multiple spills in loading/unloading are less likely.

Tables 3.5 and 3.6 show the ten most frequently spilled materials in the full HMIR file and in the multiple spill incident file respectively. The same ten materials are found on both tables and, with the exception of gasoline, the order is very close to the same.

Table 3.7 shows the most frequently spilled hazardous substances. Over thirty percent of the hazardous substance spills are anhydrous ammonia.

TABLE 3.4 - SUMMARY STATISTICS ON THE HMIR DATA AND ON THE SUBSET OF MULTIPLE SPILL INCIDENTS

	All Hazardous Material Spill Records	Records for Multiple Spill Incidents
1. Number of Reports	86,747	12,451
2. Number of Incidents	79,961	5,655
3. XAB Hazardous Substance Reports (% of File)	1,531 (1.8)	169 (1.4)
4. Mode (% of Incidents)		
Truck	91	89
Rail	8	8
Air	1	2
Other	1	1
5. Failure Code		
Unknown (% of Total)	39.6	46.9
Known (% of Known)		
External Puncture	19.6	18.3
Loose Fitting, Valve, etc.	15.8	16.8
Damage by Other Freight	13.4	17.9
Defective Fitting, valve, etc.	8.8	8.7
Loading/Unloading Spill	7.9	1.7
Dropped	7.7	7.7
Bottom Failure	6.0	5.8
Vehicular Accident	5.1	8.1

TABLE 3.5 - TEN MOST FREQUENTLY SPILLED HAZARDOUS MATERIALS

Code	Material	Spill Records	Cumulative %
8060	Paint, Enamel, Laquer, or Stain Flam. Liq.	21,036	24.2
2030	Battery Electric Storage Wet	5,991	31.2
3490	Cleaning Cmpd Liquid Corrosive	4,838	36.7
5130	Flammable Liquid N.O.S.	4,305	41.7
5360	Gasoline	4,222	46.6
3730	Corrosive Liquid N.O.S.	3,685	50.8
3560	Compd Paint Remover Flam Liq	3,565	54.9
2840	Cement Liq. N.O.S.	2,461	57.8
9930	Sulfuric Acid	2,248	60.3
9030	Resin Solution	2,011	62.7

TABLE 3.6 TEN HAZARDOUS MATERIALS MOST FREQUENTLY INVOLVED IN MULTIPLE SPILL INCIDENTS

Code	Material	Spill Records	Cumulative % of Multiple Spill Records	Material's Multiple Spill Records / Total Spill Records (%)
8060	Paint, Enamel, Laquer	3761	30.2	17.9
2030	Battery, Elec. Storage, Wet	822	36.8	13.7
3490	Cleaning Cmpd, Liq. Cor.	716	42.6	14.8
5130	Flammable Liq., N.O.S.	597	47.4	13.9
3560	Cmpd Paint Remover Flam. Liq.	589	52.1	16.5
3730	Corrosive Liq. N.O.S.	547	56.4	14.8
2840	Cement Liq. N.O.S.	397	59.7	16.1
9930	Sulfuric Acid	241	61.6	10.7
9030	Resin Solution	236	63.5	11.7
5360	Gasoline	233	65.4	5.5

TABLE 3.7 SPILL REPORTS INVOLVING THE 42 X,A,B HAZARDOUS SUBSTANCES REPORTED IN THE HMIR 1976-81

Substance	Category	Number of Spill Reports	Number of Reports involved in Multiple Spill incidents
Ammonia, Anhydrous	B	485	43
Hypochlorite Solution & Calcium Hypochlorite	B	381	56
Chlorine	A	75	7
Phosphorous White or Yellow	X	67	9
Parathion	X	65	2
Hydrogen Sulfide	B	59	3
Acrylonitrile	B	57	9
Motor Fuel anti-knock & tetra ethyl lead	B	53	11
Methyl Parathion	B	34	2
Sodium Nitrite	B	34	6
Sodium Cyanide	A	30	2
Potassium Cyanide	A	28	4
Malathion	A	19	3
Benzyl Chloride	B	18	1
Tetraethyl Pyrophosphate	B	18	0
Chlordane	X	16	1
Chlorobenzol	B	16	1
Silver Nitrate	X	14	1
Other	-	69	8
Total		1530	169

Finally, Table 3.8 shows the percentage of incidents where one, two, three, etc. packages spilled. Only about seven percent of the incidents involved spills from more than one package.

3.3 Multi-Package Spill Risk Assessment

3.3.1 Problem Statement

The probability of a hazardous substance spill relative to the probability of a spill of a hazardous material is not a particularly meaningful estimate of relative risk for two reasons. First, not all hazardous substances are included in the commodity specific HMIR data which we have extracted for this analysis. So the estimates of relative probability are likely to be inaccurate. Second and most important, the damages which result from a spill of hazardous materials may be quite different from the damages from a hazardous substance spill. Risk should measure the expected hazard or damage. Expected hazard is the probability of the event multiplied by its severity or hazard level. So, relative probability is a good measure of relative risk only when the damages from the events being compared are the same.*

* For example at the absurd level, if water were a hazardous material, it would greatly inflate the number of hazardous material spill reports and would dwarf the number of other spills in the file, but since the damage from a water spill is so slight compared to hazardous substances like aldrin or parathion, the relative probability alone would be meaningless as a measure or relative risk. A more relevant example is wet electric storage batteries and paint when shipped in packages of less than 5 gallons. These materials accounted for a large share of the spill reports but after January 1, 1981 spills of these materials do not need to be reported to MTB.

TABLE 3.8 - DISTRIBUTION OF INCIDENTS BY NUMBER OF PACKAGES SPILLED

Number of Packages Spilled	Number of Incidents	Percent of Total	Cumulative Percentage
1	74,296	92.92	92.92
2	4,831	6.04	98.96
3	652	.81	99.77
4	129	.16	99.23
5+	53	.07	100.00

With these points in mind, we have chosen to estimate the fraction of all hazardous substance spill incidents in which an RQ or more spills from multiple, small, unmarked packages.* Stated slightly differently: Given thataspill incident involving an X, A, or B hazardous substance has occurred, what is the probability that a reportable quantity spilled from multiple small unmarked packages.

There are two important characteristics of this approach which are worth noting: 1) The probabilities being compared (X, A, B spill vs. two or more small package spills of X, A, or B substances) have similar consequences;** 2) The incomplete reporting to MTB shouldn't influence the relationship between spills of a collection of substances and multiple small package spills of those substances.

The relative probability that we are estimating is the sum of 1) the probability that an RQ spills in an incident involving exactly two spills of the same X,A, or B substance, plus 2) the probability that an RQ spills in an incident involving three spills, two or more of the same X, A, or B substance, plus 3) 4 spill incidents and so on. Our approach is to estimate the probability for two spill incidents, then for three spill incidents, and so on until the additions appear to be small enough to ignore.

* In this chapter, we use "small unmarked" and "unmarked" to mean too small to require marking.

** Note that because spill size is not the same even this formulation of the problem doesn't completely reduce relative probabilities to relative risk.

For the two spill case, the probability to be estimated is the probability that an incident occurs involving exactly two spills of the same hazardous substance where each of the two spilled packages contains less than an RQ but where the combined spill exceeds an RQ, given that an incident involving an X,A, or B hazardous substance spill has occurred. Using the variable definitions presented in Table 3.9, this probability can be stated precisely as:

$$(1)\quad P(2)=\sum_{Y\in S}\Pr(t=2, k_1=y,\ k_2=y,\ w_1<RQ_y, w_2<RQ_y,\ Q_1+Q_2\geq RQ_y \mid t\geq 1, k_1 \text{ or } k_2 \in S)$$

The HMIR data contains information on all of these variables. So, one approach would be to identify all incidents involving X, A, or B hazardous substances and then to identify the subset of incidents which meet the conditions specified in equation (1). The relative frequency could be used as a measure of the relative probability. Unfortunately, there are only 1531 X, A, or B hazardous substance spills, too few to reliably measure the relative probability.

The approach which we have taken to estimate $P^{(2)}$ is to reformulate equation (1) into a set of factors which can be estimated from the data on hazardous <u>material</u> spill incidents by making some conservative approximations and some explicit

TABLE 3.9 - DEFINITIONS OF SYMBOLS IN THE PROBABILITY EQUATIONS

Definitions:

S = the set of X, A, B hazardous substances

$Y \epsilon X$ = means Y is an element of S

k_1 = 1^{st} spilled substance

k_2 = 2^{nd} spilled substance

t = number of packages spilled in the incident

w_1 = weight of the 1^{st} spilled package

w_2 = weight of the 2^{nd} spilled package

Q_1 = weight spilled from the 1^{st} package

Q_2 = weight spilled from the 2^{nd} package

RQ_y = reportable quantity for substance Y

$P^{(I)}$ = Probability that an RQ of an X, A, or B hazardous substance spilled from unmarked packages in an incident involving exactly I spilled packages, given that an incident involving an X, A, or B hazardous substance has occured.

assumptions. The Appendix presents this development. The factors result from manipulations of the form:

$$
\begin{aligned}
Pr(A,B,C) &= Pr(A,B|C)\ Pr(C) \\
&= Pr(A|B,C)\ Pr(B|C)\ Pr(C)
\end{aligned}
$$

Five assumptions were used to reformulate equation (1) into the following:

$$
\begin{aligned}
(2)\quad P^{(2)} = {} & Pr(t=2|t\geq 1)\ Pr(k_2=k_1|\ t=2) \\
& \cdot \Big[Pr(k_1 \in S_X|t\geq 1,\ k_1 \in S)\ Pr(w_1<1|t=2) \\
& \cdot Pr(w_2<1|t=2,\ k_1=k_2,\ w_1<1)\ (1-(Pr(Q<1/2|t=2, w<1))^2) \\
& + Pr(k_1 \in S_A|t\geq 1,\ k_1 \in S)\ Pr(w_1<10|t=2) \\
& \cdot Pr(w_2<10|t=2,\ k_1=k_2,\ w_1<10)\ (1-(Pr(Q<5|t=2,\ w<10))^2) \\
& + Pr(k_1 \in S_B|t\geq 1,\ k_1 \in S)\ Pr(w_1<100\ t=2) \\
& \cdot Pr(w_2<100|t=2,\ k_1=k_2,\ w_1<100)\ (1-Pr(Q<50|t=2,\ w<100))^2\Big].
\end{aligned}
$$

These five assumptions are listed in Table 3.10. All of the assumptions involve independence of a component factor to variation with the specific substance considered. Note that assumptions 3), 4), and 5) depend on RQ and that only assumptions for X substances are shown.

The first assumption is that the probability of a two spill incident is independent of the material spilled. The second assumption is that the probability that the second material spilled in a two spill incident is the same as the first material spilled is independent of the material spilled. The third

TABLE 3.10 ASSUMPTIONS IN DEVELOPING THE PROBABILITY ESTIMATES

1) $Pr(t=2 \mid t \geq 1, k_1=Y) = Pr(t=2 \mid t \geq 1)$

2) $Pr(k_2=Y \mid t=2, k_1=Y) = Pr(k_2=k_1 \mid t=2)$

3) $Pr(w_1<1 \mid t=2, k_1=Y, k_2=Y) = Pr(w_1<1 \mid t=2)$

4) $Pr(w_2<1 \mid t=2, k_1=Y, k_2=Y, w_1<1) = Pr(w_2<1 \mid t=2, k_1=k_2, w_1<1)$

5) $Pr(Q_1 \geq 1/2 \text{ or } Q_2 \geq 1/2 \mid t=2, k_1=Y, k_2 = Y, w_1<1, w_2<1) =$

$$Pr(Q_1 \geq 1/2 \text{ or } Q_2 \geq 1/2 \mid t=2, w_1<1, w_2<1)$$

assumption is that the probability that the first package spilled contained less than a pound (for X hazardous substances) is independent of the material in the shipment and of whether the two spilled materials are the same. The fourth assumption is that the probability that the second package spilled contains less than a pound (for X hazardous substances) is independent of the material spilled. Finally, the fifth assumption is that the probability that either spill is less than 1/2 pound (for X hazardous substances) is independent of the material spilled or the fact that the same material spilled from both packages.

In addition to these five assumptions, a conservative approximation was also used in the development of equation (2). This approximation involves the probability that the sum of the two spills Q_1 and Q_2 will exceed an RQ. Obviously either Q_1 or Q_2 must exceed 1/2 RQ if the sum is to exceed RQ, but one could exceed 1/2 RQ while the sum was less than RQ. The conservative approximation is:

$$\Pr(Q_1 + Q_2 \geq RQ) = \Pr(Q_1 \geq 1/2\ RQ\ \underline{\text{or}}\ Q_2 \geq 1/2\ RQ)$$

The probability that the sum of the spills exceeds an RQ is approximated by the probability that one of the two spills exceeds 1/2 RQ. This is taken further in equation (2) where the probability that one of the spills exceeds 1/2 RQ is replaced by one minus the probability that both spills are less than 1/2 RQ.

3.3.2 Measuring the Factors

Evidence on the validity of the assumptions in Table 3.10 is presented below in Table 3.13, but before that evidence is presented the measures used to estimate each factor must be defined. Table 3.11 defines the terms used in Table 3.12 which shows the measures used for the factor probabilities in equation (2). Note that for each factor probability the numbers are defined over the set of spill records for which all needed data was available. This permitted the largest sample of spills to be used in calculating each factor, but as a result the variables used are not precisely the same in each measure. For example, the R_1 used in estimating $Pr(t=2|t\geq1)$ is somewhat different from the R_1 used in estimating $Pr(w<1|t\geq1)$ because S_1 is not available for all spill records.

A conservative assumption has been introduced into the measurement of the probability that 1/2 RQ spills from one of the packages. Notice in the definition of F_1 that rather than a 1/2 RQ spill a 1/2 shipment spill is used. This is equivalent to assuming that all shipments of less than an RQ contain exactly an RQ.

The variables used to measure the factor probabilities can be accumulated over a variety of sets of spill records. The largest set is the set of all hazardous material spills. The set of all hazardous substance spills is much smaller but also of

TABLE 3.11 DEFINITIONS USED TO MEASURE RELATIVE FREQUENCIES

R_1 = number of one spill incident records. (1 rec./incident)

R_2 = number of two spill incident records. (2 rec./incident)

R_3 = number of three spill incident records. (3 rec./incident)

R_{22} = number of two spill incident records where the same material spills in both records.

S_1 = number of records where the shipment weight is less than one pound.

G_1 = number of records where the same material spilled in a two spill incident and where both spills were from packages with a shipment weight of less than one pound.

H_1 = number of records that have shipment weights of less than one pound where the same material spilled in a two spill incident.

F_1 = number of records where the shipment weight is less than one pound and less than half of the shipment spilled.

X = number of category X hazardous substance records.

TABLE 3.12 MEASURES OF PROBABILITIES: RELATIVE FREQUENCIES

$$P_r(t=2 \mid t \geq 1) \simeq \frac{R_2/2}{R_1 + R_2/2 + R_3/3}$$

$$P_r(k_2 = k_1 \mid t=2) \simeq \frac{R_{22}}{R_2}$$

$$P_r(w_1 < 1 \mid t \geq 1) \simeq \frac{S_1}{R_1 + R_2 + R_3}$$

$$P_r(w_2 < 1 \mid t=2, k_1 = k_2, w_1 < 1) \simeq G_1/H_1$$

$$P_r(Q_1 \geq 1/2 \text{ or } Q_2 \geq 1/2 \mid t=2, w_1 < 1, w_2 < 1) \simeq$$

$$1 - (P_r(Q < 1/2 \mid t \geq 1, w < 1))^2 \simeq 1 - \left(\frac{F_1}{S_1}\right)^2$$

$$P_r(k_1 \in S_x \mid t \geq 1, k_1 \in S) \simeq \frac{X}{X+A+B}$$

Similar measures are developed for A and B substances.

interest. Further, the measures can be calculated for individual materials to examine the variability of the estimates of the factor probabilities with material. This is a way of qualitatively testing the key assumption of independence of material which was used to develop equation (2). Obviously, the smaller the sample the more the factor probability estimates will be influenced by the "random noise" or "sampling error" in the sample.

Table 3.13 presents estimates of the factor probabilities. Four estimates are presented. The first two are averages over all hazardous material and hazardous substance spill incidents. The next two estimates are selected from the commodity specific factors. In the median estimate 50% of the commodities have factors of smaller size and 50% have factors of larger size. In the 90% case, 90% of the commodities have factors of smaller size and only 10% have larger factors. In these last two estimates each estimate is selected separately so different commodities are used for each factor. Where a factor probability is nearly constant over the four columns, as in the case of the first factor, the corresponding assumption is supported. If the factor is not constant over the columns the assumption is more doubtful though at least part of the variation is caused by "random noise" or sampling error.

The similarities between the estimates of the factors calculated over all hazardous substance incidents and over all hazardous material incidents suggests that in aggregate hazardous

TABLE 3.13 ESTIMATES OF THE FACTOR PROBABILITIES

Factor	Average for all X,A, or B Hazardous Substance Spill Incidents	Average for all Hazardous Material Spill Incidents	Median for all Hazardous Materials	90 Percentile for all Hazardous Materials
$P_r(t=2 \mid t\geq 1)$	.0406 (1)	.0606 (3)	.0605 (5)	.0804 (5)
$P_r(k_2=k_1 \mid t=2)$	.4870 (1)	.3886 (3)	.2917 (5)	.7225 (5)
$P_r(w_1<1 \mid t\geq 1)$	.0000 (2)	.0009 (4)	.0000 (5)	.0024 (5)
$P_r(W_2<1 \mid t=2, k_1=k_2, w_1<1)$	1.000 *	1.000 *	1.000 *	1.000 *
$1-(P_r(Q<1/2 \mid t\geq 1, w<1))^2$	1.000 *	.9600 (4)	1.000 *	1.000 (5)
$P_r(w_1<10 \mid t\geq 1)$	.0198 (2)	.0315 (4)	.0234 (5)	.1121 (5)
$P_r(W_2<10 \mid t=2, k_1=k_2, W<10)$	1.000 *	.5385 (4)	1.000 *	1.000 *
$1-(P_r(Q<5 \mid t\geq 1, w<10))^2$	.8457 (2)	.8209 (4)	.7934 (5)	1.000 (5)
$P_r(w_1<100 \mid t\geq 1)$	.0989 (2)	.1547 (4)	.1383 (5)	.3578 (5)
$P_r(W_2<100 \mid t=2, k_1=k_2, W_1<100)$	1.000 *	.6531 (4)	.5106 (6)	1.000 (6)
$1-(P_r(Q<50 \mid t\geq 1, w<100))^2$	.3485 (2)	.4813 (4)	.4861 (5)	.7256 (5)

1) - Calculated over the 1416 X,A, or B Hazardous Substance Spill Incidents.
2) - Calculated over the 1145 X,A, or B Hazardous Substance Spill Incidents with good spill and shipment size data.
3) - Calculated over the 79,700 Hazardous Material Spill Incidents.
4) - Calculated over the 44,699 Hazardous Material Spill Incidents with good spill and shipment size data.
5) - Measured over the 72 materials with over 100 incidents.
6) - Measured over the 31 materials with over 10 matching-material, 2-spill incidents.

* - Sample did not contain adequate information. Upper bound of 1.0 used.

substance and material spill incidents are similar. In percentage terms, the largest discrepancies arise in factors involving shipment size $(Pr(w_1 < RQ \mid t \geq 1))$. The dominance of anhydrous ammonia in the hazardous substance incidents probably account for the discrepancy because it is shipped in large shipment sizes.

The similarities between the average and median estimates for the hazardous materials indicate that a few unusual hazardous materials are not dominating the spill data. The 90 percentile estimates give an indication of the range of factor values which can be expected. As mentioned earlier, some of the differences between the median and 90 percentile estimates is the "random noise" or sampling error which results from the small number of spills over which the factors are calculated. Some of the difference is undoubtedly due to real differences in the way specific materials are shipped and their susceptibility in spill incidents.

3.3.3 Results

The factor probabilities can be used in equation (2) along with the portion of all X, A, or B hazardous substance spills that belong to each category $(Pr(k_1 \in S_X \mid k_1 \in S))$, to estimate $P^{(2)}$. Table 3.14 presents these estimates of $P^{(2)}$ along with estimates of the probability that a multiple small package incident releases an RQ given an X, an A, or a B hazardous substance spill. For the first three sets of factor estimates the estimates of $P^{(2)}$ are very similar. $P^{(2)}$ given an X hazardous

TABLE 3.14 - RESULTS: RQ SPILLS FROM TWO SPILL INCIDENTS

Factor Estimates	$P^{(2)}$, Probability that a RQ spills from two Unmarked Packages Given			
	X Spill	A Spill	B Spill	Spill of Some X,A,B Substances
Average all Hazardous Substance Spill Incidents	0.0	$3.3X10^{-4}$	$6.8X10^{-4}$	$5.7X10^{-4}$
Average all Hazardous Material Spill Incidents	$2.0X10^{-5}$	$3.3X10^{-4}$	$1.1X10^{-3}$	$9.3X10^{-4}$
Median for all Hazardous Materials	0.0	$3.3X10^{-4}$	$6.1X10^{-4}$	$5.1X10^{-4}$
90 Percentile for all Hazardous Materials	$1.4X10^{-4}$	$6.5X10^{-3}$	$1.5X10^{-2}$	$1.2X10^{-2}$

substance spill is the only exception. The extremely low frequency of shipments weighing less than a pound resulted in no observations in the hazardous substance sample and none for the median material either. All other estimates are quite close, within a factor of two. These results again suggest that the results using the average hazardous material factors produce reasonable estimates of hazardous substance spill probabilities. <u>In the remainder of the report, we will concentrate the analysis on probability estimates developed from the average factors calculated from the set of all hazardous material spills.</u>

The 90 percentile factor estimates produce estimates of $P^{(2)}$ which are substantially higher than the other three estimates. The 90 percentile factor estimates should be interpreted as an estimate of the range of the commodity specific spill probabilities which is consistent with the average estimate. Table 3.15 shows the same 90 percentile estimates of $P^{(2)}$ as in Table 3.14 but also shows the highest estimate of $P^{(2)}$ developed for single materials. These estimates are developed from the factors for a <u>single</u> material. Ammonium hydroxide has the highest $P^{(2)}$ of all hazardous materials and the $P^{(2)}$ is about the same as the 90 percentile estimate. This is a little misleading, however, because 1.0 was used as the factors: $Pr(w_2 < RQ | t=2, k_1=k_2, w_1 < RQ)$ for all materials because most of the single material samples were too small to estimate this factor. Calcium hypochlorite is the X, A, or B hazardous substance with the highest estimate of $P^{(2)}$.

TABLE 3.15 - RESULTS: Possible Variations with Material

	Probability that a RQ Spills from two unmarked packages given:			
	X Spill	A Spill	B Spill	Spill of Some X A B Substance
90% Factors*	1.4×10^{-4}	6.5×10^{-3}	1.5×10^{-2}	1.2×10^{-2}
Highest single hazardous material (Ammonium hydroxide < 45% ammonia)				1.1×10^{-2}
Highest single X,A,B hazardous substance (Calcium Hypochlorite Mixture)				1.2×10^{-3}

*Each factor used in calculating the probability was chosen so that 90% of the hazardous materials had factors with lower values.

The estimates of $P^{(2)}$ in Table 3.14 suggest that the probability of an RQ spill from multiple unmarked packages is small, 10^{-3}. However, three and four and more spill probabilities must be added to the estimates of $P^{(2)}$ to obtain the full probability. $P^{(3)}$ and $P^{(4)}$ cannot be ignored a-priori because there are two factors which change in different directions and which influence the size of these higher-spill probabilities. First, higher-spill incidents are much rarer than two spill incidents. However, when more packages spill an RQ spill is more likely to result. Table 3.16 presents the contributions of two, three, and four spill incidents to the total estimated probability that a hazardous substance spill will be an RQ spill from multiple unmarked packages. The factors used to calculate these probabilities are presented in Table 3.17*.

* $P(3)$ and $P(4)$ given an X hazardous substance spill are given by the following formula:

$$P_x(3) = U_1 \{(U_3.X_5.X_6.X_7) + (U_8.X_{10}.X_{11}.X_{12}.X_{13})\}$$

$$P_x(4) = U_2.\{(U_4.X_5.X_6.X_7) + (U_9.X_{10}.X_{11}.X_{12}.X_{13}) + (U_{14}.X_{15}.X_{16}.X_{17}.X_{18}.X_{19})\}.$$

The subscripts refer to the factor numbers in Table 3.17. The U means that the factor is drawn from the "All" column. The X means that the factor is drawn from the "X Spill" column. Similar expressions are used for $P_A(3)$, $P_A(4)$, $P_B(3)$, and $P_B(4)$.

TABLE 3.16 - Results: Contribution of Number of Spills*

	Probability that a RQ Spills from Multiple Unmarked Packages Given:			
	X Spill	A Spill	B Spill	Spill of Some Substance
$P^{(2)}$	$2.0x10^{-5}$	$3.3x10^{-4}$	$1.1x10^{-3}$	$9.3x10^{-4}$
$P^{(3)}$	$3.1x10^{-6}$	$5.3x10^{-5}$	$2.1x10^{-4}$	$1.7x10^{-4}$
$P^{(4)}$	$8.6x10^{-7}$	$1.5x10^{-5}$	$6.7x10^{-5}$	$5.4x10^{-5}$
Total	$2.4x10^{-5}$	$4.0x10^{-4}$	$1.4x10^{-3}$	$1.2x10^{-3}$

*Averaged over all hazardous material spills

TABLE 3.17 - THREE AND FOUR SPILL INCIDENT FACTORS

Factor	X Spill	A Spill	B Spill	Used for All
1. $Pr(t=3 \mid t\geq 1)$				.0082
2. $Pr(t=4 \mid t\geq 1)$				.0016
3. Pr(2 spills of same material $\mid t=3$)				.2332
4. Pr(2 spills of same material $\mid t=4$)				.2214
5. $Pr(w_1<RQ \mid t\geq 1)$	.0009	.0315	.1547	
6. $Pr(w_2<RQ \mid t=2,k_1=k_2,w_1<RQ)$	1.0000*	.5385	.6531	
7. $1-(Pr(Q<RQ/2 \mid t\geq 1,w<RQ))^2$	.9600	.8209	.4813	
8. Pr(3 spills of same material $\mid t=3$)				.1995
9. Pr(3 spills of same material $\mid t=4$)				.1748
10. $Pr(W_1<RQ\ t\geq 1)$	.0009	.0315	.1547	
11. $Pr(W_2<RQ \mid t=2,k_1=k_2,W,<RQ)$	1.0000*	.5385	.6531	
12. $Pr(W_3<RQ \mid \ldots)^*$	1.0000*	1.0000*	1.0000*	
13. $1-(Pr(Q<RQ/3 \mid t\geq 1, W<RQ))$	.9962	.9380	.6923	
14. Pr(4 spills of same material $\mid t=4$)				.2097
15. $Pr(W_1<RQ \mid t\geq 1)$	.0009	.0315	.1547	
16. $Pr(W_2<RQ \mid t=2,k_1=k_2,W_1<RQ)$	1.0000*	.5385	.6531	
17. $Pr(W_3<RQ \mid \ldots)^*$	1.0000*	1.0000*	1.0000*	
18. $Pr(W_4<RQ \mid \ldots)^*$	1.0000*	1.0000*	1.0000*	
19. $1-(Pr(Q<RQ/4 \mid t\geq 1,W<RQ))^4$	1.0000	.9910	.8816	

* Upper bound of 1.000 used.

Averaged over all hazardous materials spills

As the numbers in the table indicate, the contributions of three and four spill incidents add only about 30% to the $P^{(2)}$ estimate and the contribution drops off by about a factor of five with each increase of one in the number of packages spilled in the incident. Five and more spill incidents can safety be ignored.

The total probability, 1.2×10^{-3}, is very small. The 42 X, A, or B hazardous substances which are reported in the HMIR were involved in 1531 spills over the period January 1976 through August 1981. Over this five and one half year period then, we would expect roughly two spills of an RQ from multiple spill incidents involving unmarked packages of these 42 hazardous substances. Actually, none were reported.

Only half of the X, A, or B hazardous substances designated under the Clean Water Act are in the HMIR data and without knowing the total spills of the unreported half we cannot estimate the total number of RQ spills from unmarked packages. Further, new designations of hazardous substances by EPA under CERCLA will also increase the number of X,A, or B hazardous substance spills. The increases in hazardous substance spills will increase the expected number of RQ spills from unmarked packages in a ratio of about 800 to 1*. Of every 800 hazardous substance spills one is expected to be an RQ spill from small unmarked packages.

3.3.4 Other Measures

Without being able to estimate the total number of RQ spills from unmarked packages, an important statistic in attempting to judge the acceptability of these spill probabilities is: the fraction of reportable** incidents which would go unreported because the spill came from multiple unmarked packages. This fraction is different from the 1.2×10^{-3} cited above because not all hazardous substance incidents result in spills of a reportable quantity. In fact, only 27% of the incidents spill more than 100 lbs, 53% spill more than 10 lbs., and 90% spill more than one pound.*** These percentages are used with the

---

* As the proportion of X,A,B hazardous substance spills which fall into each category changes from the .1109X, .1135A, .7756B which were found in the HMIR data, the expected rate of increase in RQ spills from unmarked packages will also vary. The $1.2\text{X}10^{-3}$estimates is $.1109 \times 2.4\text{x}10^{-5} + .1135 \times 4.0 \times 10^{-4} + .7756 \times 1.4\text{X}10^{-3}$; $1.2/1000 \simeq 1/800$

** By reportable we mean spills of more than a reportable quantity. The regulations currently require reporting to NRC only when an RQ spills from a single package.

*** These percentages are calculated over all spill reports in the HMIR data, and cover all hazardous materials.

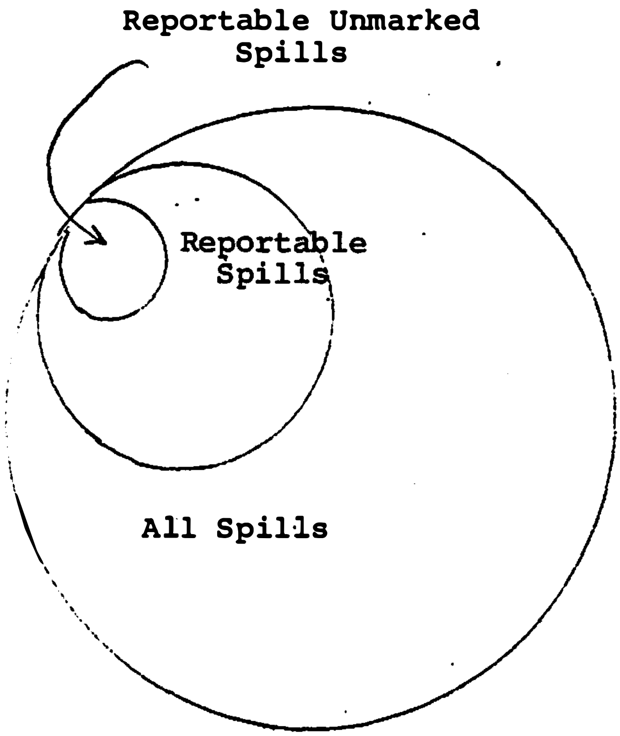
probabilities in Table 3.16 to calculate the fraction of <u>reportable</u> incidents which would go unreported because the spills were from unmarked packages. Figure 3.1 illustrates these relationships for B hazardous substances and Table 3.18 presents the results for X, A and B hazardous substances. Roughly one in 75,000 reportable X hazardous substance spills would be from unmarked packages, six in 10,000 reportable A hazardous substances incidents would be from unmarked packages, and 5 in 1,000 reportable B hazardous substance incidents be from unmarked packages. All of these fractions are small and are probably much smaller than the fraction of incidents which are not reported for other reasons.

One of the reasons for non-reporting could be that a spill of less than an RQ from a <u>marked</u> package is added to a spill from an unmarked package. In this case the operator of the vehicle would know that a hazardous substance had spilled but he would be unaware that an RQ had spilled. Table 3.19 presents estimates of the fraction of reportable spills which result from spills of less than an RQ from a marked package and a spill from an unmarked package. These fractions are roughly the same size as the fraction of reportable spills from multiple spills of unmarked packages.

The table also presents the fraction of reportable spills which are from multiple spills of <u>marked</u> packages where less than an RQ spills from each package. Under the MTB's regulations these incidents do not need to be reported even though an RQ

Figure 3.1

Relationship Among All Spills, Reportable Spills, and Reportable Spills from Unmarked Packages for B Hazardous Substance.



1. $\frac{\text{Reportable}}{\text{All}} = .27$

2. $\frac{\text{Reportable, Unmarked}}{\text{All}} = 1.4\text{x}10^{-3}$

3. $\frac{\text{Reportable, Unmarked}}{\text{Reportable}} = \frac{1.4\text{x}10}{.27} = 5.3\text{x}10^{-3}$

TABLE 3.18 - FRACTION OF REPORTABLE SPILLS FROM UNMARKED PACKAGES

Probability that a RQ Spills from Multiple Unmarked Packages Given <u>an RQ Spill</u> of:

	X	A	B
Average Overall Spills	2.7×10^{-5}	7.5×10^{-4}	5.3×10^{-3}
	(1 in 37,000)	(1 in 1300)	(1 in 190)

Fraction of Spills which are greater than:

1 pound	.898
10 pounds	.533
100 pounds	.266

TABLE 3.19 - FRACTION OF REPORTABLE TWO SPILL INCIDENTS WHICH MIGHT NOT BE REPORTED BECAUSE NO SINGLE PACKAGE SPILLED AN RQ.

Two Spill Incidents where less than An RQ spills from each package but the sum of spills exceeds an RQ.	Fraction of X Spills	Fraction of A Spills	Fraction of B Spills
1) 1 marked and 1 unmarked package	2.4×10^{-6}	5.4×10^{-4}	3.6×10^{-3}
2) 2 marked packages	2.7×10^{-3}	1.8×10^{-2}	2.1×10^{-2}
Total	2.7×10^{-3} (1 in 370)	1.9×10^{-2} (1 in 50)	2.5×10^{-2} (1 in 40)

spilled in the incident. This fraction is much larger than the fraction from a marked and an unmarked package or from two unmarked packages. Table 3.20 presents the factors used to calculate the fractions reported in Table 3.19.

Another interpretation of these fractions is useful. We argued earlier, in section 2.5, that because only "RQ" needs to be marked on a package, all spills from a marked package would probably be reported to the NRC. Thus, spills of less than an RQ from marked packages would be reported. If the marking requirement were changed to include the category of the hazardous substance in the package("RQ-X" , "RQ-A" etc.), then spill of less than an RQ would not be reported and the fractions in Table 3.19 represent the fraction of reportable spills which would go unreported because of this change.

3.4 Conclusions

The fraction of all <u>hazardous substance spill</u> incidents which involve RQ spills from small unmarked packages is very small, probably less than one in one thousand. The fraction of <u>reportable incidents</u>* is larger, but still small, about one in 200. As new hazardous substances are added the number of hazardous substance spills will increase and the frequency of RQ spills from unmarked packages will increase as well. However,

*Reportable incidents are incidents where more than an RQ spills. They can involve single spill incidents as well as multiple spill incidents.

TABLE 3.20 - FACTORS USED TO ESTIMATE OTHER UNREPORTED INCIDENT FRACTIONS

$P_x^{(2)}$ - a marked and an unmarked package = $U_1 \cdot U_2 \cdot X_3 \cdot X_4 \cdot X_5(1-X_6 \cdot X_7)$

	X	A	B	All
1) $Pr(t=2 \mid t \geq 1)$				.0606
2) $Pr(k_1=k_2)$				.3886
3) $Pr(W_1 \geq RQ \mid t=2)$	.9991	.9685	.8453	
4) $Pr(W_2 < RQ \mid t=2, W_1 \geq RQ)$	.0009	.0315	.1547	
5) $Pr(Q_1 < RQ \mid W_1 \geq RQ)$	.1018	.4495	.6829	
6) $Pr(Q_1 < 1/2\ RQ \mid Q_1 < RQ, W_1 \geq RQ)$	0.000*	.2337*	.7609*	
7) $Pr(Q_2 < 1/2\ RQ \mid W_2 < RQ)$	.2000	.4224	.7203	

* Upper bound used .1RQ rather than 1/2 RQ.

$P_x^{(2)}$ - two marked packages = $U_1 \cdot U_2 \cdot X_3 \cdot X_4 \cdot X_5 \cdot X_6(1-(X_7)^2)$

	X	A	B	All
1) $Pr(t = 2 \mid t \geq 1)$				.0606
2) $Pr(k_1=k_2)$				.3886
3) $Pr(W_1 \geq RQ \mid t=2)$	.9991	.9685	.8453	
4) $Pr(W_2 \geq RQ \mid t=2, k_1=k_2, W_1 \geq RQ)$	1.0+	1.0+	1.0+	
5) $Pr(Q_1 < RQ \mid W_1 \geq RQ)$	.1018	.4495	.6829	
6) $Pr(Q_2 < RQ \mid \ldots .)$	1.0+	1.0+	1.0+	
7) $Pr(Q < 1/2\ RQ \mid Q < RQ, W \geq RQ)$	0.0*	.2337*	.7609*	

* Upper bound used .1RQ rather than 1/2 RQ

\+ Upper bound of 1.0 used.

Note: These fractions produce estimates of the fraction of All hazardous substance spills. To obtain the fraction of reportable spills, the fraction of all spills must be divided by the fraction of all spills which are reportable for each spill size (see Table 3.18).

over the five and one half years when data was collected on spills of 42 of the 92 Clean Water Act X,A, or B hazardous substances no incidents of RQ spills from small unmarked packages were reported.

Current regulations require reporting to NRC only when an RQ spills from a single package. So, incidents involving multiple spills from marked packages could go unreported even if more than an RQ spilled in total because no single package spilled an RQ. Less than 2.5 percent of all "reportable" incidents involve two small (<RQ) spills, one or both of which are from a marked package.

In Section 2.5 we argued that spills of less than an RQ from marked packages will probably be reported because the category of the hazardous substance is not included on the marking or shipping paper. It could be argued that less than 2.5% of the incidents where more than an RQ spilled would be unreported if the regulations were changed to include the category of hazardous substance ("RQ-X" etc.) on the marking and shipping papers. That is, the current marking regulations probably result in more reporting than is strictly required under the regulations. If the marking requirements were changed to eliminate this "over reporting", less than 2.5% of the RQ spills would be unreported.

There are two qualifications to these general conclusions. First, significant underreporting has been indicated as a major problem in the HMIR data. If this underreporting were entirely in small shipment size categories then the estimated probabilities of an RQ spill from unmarked packages could be low by an order of magnitude. Though it seems unlikely that unreported incidents would concentrated in this way, even an order of magnitude increase results in small estimates of the fraction of all RQ spills, which were from unmarked packages; less than five percent.

Second, because relative risk is measured as the product of the hazard of the event and the probability of the event and because reportable spills are on average much larger than the spills from multiple small spill incidents, the fractions of reportable incidents cited above are conservative upper bounds on the relative risk of multiple small package spill incidents.

4.0 Large Dilute Spill Risk

This section presents some data from the U.S. Coast Guard's Pollution Incident Reporting System (PIRS) and from MTB's HMIR on the frequency of RQ or larger spills from dilute unmarked shipments. Recall that the threshold concentrations of mixtures and solutions qualifying as hazardous substances were set so that exactly a RQ is spilled if 50,000 pounds of the solution is spilled. (See Table 1 on page 2.) That is, the threshold concentration is RQ ÷ 50,000. Shipments with concentrations above these thresholds require marking. Shipments with concentrations below the thresholds do not require marking.

4.1 Probability Factors

There are two major factors which can be used to estimate the fraction of spills which are RQ spills from dilute unmarked packages. The first is the probability that a particular substance is shipped in a concentration below the threshold for its category of hazardous substance, RQ÷50,000. The second is the probability that the concentration times the spill size is greater than an RQ. Using the definitions in Table 4-1, this is:

$$(4.1)\quad P = \sum_{Y \in S} \left(Pr(k=Y \mid Y \in S)\ Pr\ (C<RQ_Y/50{,}000, \mid k=Y)\ Pr(C\times Q \geq RQ_Y \mid C<RQ/50{,}000,\ k=Y)\right)$$

Unfortunately neither PIRS nor HMIR data gives any indication of the concentration of the hazardous material being shipped except for selected materials where certain thresholds

TABLE 4.1 DEFINITIONS

S = the set of X,A,B hazardous substances.

k = the material spilled in the incident.

C = the concentration of the material spilled, fraction by weight.

RQ_Y = the reportable quantity for material Y, in pounds.

Q = the weight spilled in the incident.

P = Probability that an RQ or more spills from a dilute, unmarked shipment.

are used to specify different hazard classes.* So the second term, $Pr(C<RQ_y/50{,}000 \mid k=y)$, cannot be estimated from these data sources.

In most situations, shippers would prefer to ship more concentrated forms because the transport cost rises with the weight shipped. The exception is where concentrating the material costs more than the added shipping cost and where the material can be used in the dilute form. Wastes are a class of materials that meet these requirements. Another class is where the hazardous substance is an additive to other valued materials which are not hazardous substances. Tetraethyl lead is an example of a hazardous substance added to gasoline. While these exceptions are important, most materials are probably <u>not</u> shipped regularly in dilute concentrations. That is, $Pr(C<RQ_y/50{,}000)$ is small, but for the purpose of developing an upper bound on the probability of an RQ spill from a dilute unmarked shipment, let this factor be one.

$Pr(C<RQy/50{,}000 \mid k=Y) = 1$

An additional conservative approximation for the last factor in the equation is that the concentration is <u>equal</u> to the threshold for marking: $C = RQy/50{,}000$. Using this approximation and the previously stated, improbably conservative assumption equation 4.1 can be restated:

$$(4.2) \qquad P << \sum_{Y \in S} Pr(k=Y \mid Y \in S) \times 1.0 \times Pr(Q \geq 50{,}000 \mid k=Y)$$

* Ammonium hydroxide for example has three categories 1) Ammonia solution, 44% ammonia is a non-flammable gas, 2) Ammonium hydroxide between 12% and 44% is a corrosive liquid, and 3) less than 12% is an ORM A.

If we assume that the probability of a spill greater than 50,000 pounds is independent of the specific substance under consideration:.

$$P_r(Q \geq 50{,}000 \mid k=Y) = P_r(Q \geq 50{,}000)$$

Then:

$$(4.3) \qquad P \ll Pr(Q \geq 50{,}000) \sum_{Y \in S} Pr(k=Y \mid Y \in S).$$

Since $\sum_{Y \in S} P_r(k=Y \mid Y \in S) = 1$, these assumptions lead to the probability that a spill exceeds 50,000 pounds as a <u>very</u> conservative upper bound on the probability that an RQ spills from a dilute unmarked shipment given that a hazardous substance has spilled.

$$(4.4) \qquad P \ll P_r(Q \geq 50{,}000)$$

Table 4.2 summarizes the assumptions leading to this upper bound.

Table 4.3 presents data from HMIR and PIRS on the frequency of spills of 50,000 pounds or more. As expected, truck spills of this size are very infrequent. Five percent (5%) of rail spills exceed this size. Roughly five percent (5%) of the PIRS spills exceed this weight, but the PIRS data cover spills from many sources. As Table 4.4 shows, the largest spills are from non-transportation sources which are storage and production facilities. Thus, 4.7 percent overstates the fraction of transportation incidents where 50,000 pounds spill.

Table 4.2 Assumptions Used to Develop the Loose Upper Bound

1. $P_r(C<RQ_Y/50{,}000 \mid k=Y) = 1$

The concentration of the hazardous substance in the shipment is below the threshold where regulations apply. This is an extreme assumption used only becuase of a complete lack of data.

2. $C = RQ_Y/50{,}000$

The concentration is right at the threshold. This is also a conservative assumption needed to construct the upper bound.

3. $P_r(Q \geq 50{,}000 \mid k=Y) = P_r(Q \geq 50{,}000)$

The probability that a spill exceeds 50,000 pounds is independent of the substance under consideration. While not true, this assumption may be reasonable in developing estimates of aggregate probabilities.

TABLE 4.3 SPILLS OF MORE THAN 50,000 POUNDS

Source	Number	Avg. per Year	Percent of Incidents
HMIR - Truck (1976-81)	526	96	0.8
HMIR - Rail (1976-81)	305	55	4.9
PIRS (except oil) (1977-80)	119	30	4.7

PIRS data is taken from "Polluting Incidents in and Around U.S. Waters" by the U.S. Coast Guard.

TABLE 4.4 SOURCE OF SPILLS IN PIRS
(except oil)

Source	1979 Number	1979 Volume (k gal)	1979 Avg. Size (lbs)*	1980 Number	1980 Volume (k gal)	1980 Avg. Size (lbs)*
Vessels	211	112	4,246	151	73	3,868
Land Vehicle	47	85	14,468	47	78	13,277
Non-Transp.	251	2,316	73,817	168	516	24,571
Marine Transfer	47	50	8,511	38	70	14,737
Other Known	33	4	970	22	52	18,909
Total Known	589	2,567	34,866	426	788	14,798
Total Unknown	1555	593	3,052	1315	98	594
Spills of More Than 5,000 gal.	31	3070+	792,129	21	750+	285,602

*At eight pounds per gallon.

+Some spills are from unknown sources.

Source: "Polluting Incidents In and Around U.S. Waters, Calendar Year 1979 and 1980" U.S. Coast Guard.

4.2 Summary

In summary, without data on the fraction of spills which are more dilute than RQ ÷ 50,000, and on the spill size distribution for these dilute solutions, the risk of RQ spills from dilute, unmarked shipments cannot be estimated. The relative spill probability can be bounded, however. Five percent of rail spills, much less than five percent of the spills into water from transportation sources, and less than one percent of truck spills exceed 50,000 pounds, and the fraction of all spills exceeding 50,000 pounds is a very loose upper bound on the fraction of spills which exceed an RQ from dilute unmarked packages.

Because of the shipping costs, the concentration of a material used and the costs of concentrating a material it is likely that only hazardous wastes and a handful of additives would be economically shipped in dilute form. Further research should focus on identifying specific materials which are shipped in these low concentrations, and at understanding the costs and trade offs between concentrating and transporting.

5.0 Non-Compliance with Hazardous Materials Regulations

As mentioned in the introduction, packages containing hazardous substances may be unmarked for any of three reasons: (1) they may contain less than an RQ, (2) they may be so dilute that they do not require marking, and (3) they may not be in compliance with the existing regulations. Section 3.0 addressed the risk of multiple small package spills and Section 4.0 discussed the risk of large dilute spills. This section is concerned with non-compliance, particularly with non-compliance which leaves the public at risk because of unreported spills. More specifically, spills would probably not be reported if shipping paper and marking regulations are not followed, because these activities provide the carrier with knowledge of the shipment's hazard.

This section consists of four parts. The first presents data on non-compliance. The second discusses reasons for non-compliance with emphasis placed on the cost of complying with the regulations. The third section is concernced with the possible effects on compliance of hazardous substance designation under the CERCLA legislation. The final part summarizes the findings.

5.1 Data on Non-Compliance

Very few sources of data exist to document the extent of non-compliance with the hazardous materials regulations. According to a report by the Comptroller General of the U.S., neither MTB nor the modal administrations compiles statistics on total violations found in field inspections. Even if this information was compiled, the rate of non-compliance would be difficult to determine because a complete inventory of those active in the hazardous materials industry is not available and small enforcement staffs can inspect only a small percentage of the known carriers/shippers. DOT has estimated, however, that there are:

-21,000 hazardous material container manufacturers

-100,000 locations from which shipments in portable tanks originate

-4,370 locations from which bulk shipments originate

-600,000 bulk transport vehicles

-700,000 vehicles used to transport portable tanks.*

Several studies present statistics on violations of hazardous material regulations. Their findings are reviewed below.

*Report by the Comptroller General of the United States."Programs for Ensuring the Safe Transportation of Hazardous Materials Need Improvement." November, 1980.

The National Transportation Safety Board (NTSB) reports the results of on-the-road inspections conducted by the Bureau of Motor Carrier Safety (BMCS) of the Federal Highway Administration.* In May 1979, at a roadside check at a major crossing of the Mississippi River, 297 vehicles (17% of the total vehicles inspected) carried hazardous materials. Inspectors found 291 violations of the hazardous materials regulations, including 16 which caused the vehicles to be placed out-of-service. NTSB also reports that in FY 1980, BMCS conducted 3,489 inspections of hazardous materials trucks. The most frequently cited hazardous materials violations involved shipping papers and placarding. Also, a review of 43 selected case reports on hazardous materials carriers (FY 1980) showed 74 violations of the Federal hazardous material regulations. Thirty-seven (37) or 50% of the violations involved shipping paper, placarding or labeling errors.

The most comprehensive study of motor vehicles carrying hazardous materials was conducted in Virginia in 1977 and 1978.** All trucks passing inspection points on several primary and interstate roadways were stopped. Although the main purpose

*National Transportation Safety Board, "Safety Effectiveness Evaluation: Federal and State Enforcement Efforts in Hazardous Materials Transportation by Truck," 1981.

**Price, Schmidt and Kates, "Multi-Modal Hazardous Materials Transportation in Virginia," Sept. 1981.

of the study was to develop hazardous material commodity flow data, compliance with hazardous material shipping paper and placarding requirements was checked. Table 5.1 presents the results of this survey. In 1977, 41.0% of the trucks requiring placards had placarding violations; in 1978 this rate was 34.5%. In addition, a vehicle is in violation of the regulations if it is placarded when not required, e.g. it is not carrying a large enough quantity or it is not carrying a hazardous material at all. In 1977, 13% of the all placard violations were of this type wheras in 1978 2% were of this type.

In 1977, 23.1% of the trucks carrying hazardous materials had no freight bills while 9.4% had no bills in 1978. The non-compliance rate was better than that for all trucks, 35.4% of which in 1977, and 36% of which in 1978 carried no freight bills.

5.2 Reasons for Non-Compliance

Although the reasons for non-compliance with hazardous materials regulations are not well documented, the NTSB conducted a survey of federal agencies, private industry and trade and labor organizations to gain information on this topic.* The opinions expressed in interview and questionaires differed somewhat, but there was agreement in six areas about the perceived reason for non-compliance. These include the following:

*National Transportation Safety Board, "Special Study: Non-compliance with Hazardous Materials Safety Regulations," 1979.

Table 5.1: Summary of 1977 and 1978 Virginia Truck Survey Results

		1977	1978
1.	Total Trucks Surveyed	4452	4862
2.	Trucks with Hazardous Materials	594	351
3.	Trucks Requiring Placarding	429	322
4.	Trucks with Placard Violations	202	192
5.	Violations by Trucks Requiring Placards	176	111
6.	Trucks without Freight Bills	1577	1754
7.	Trucks with Hazardous Materials and without Freight Bills	137	33
8.	Trucks Requiring Placards which had Violations	41.0%	34.5%
9.	Trucks with Hazardous Materials, without Freight Bills	23.1%	9.4%
10.	All Trucks without Freight Bills	35.4%	36.1%

Source: Price, Schmidt and Kates, "Multi-Modal Hazardous Materials Transportation in Virginia," Sept. 1981

1. Complexity of the regulations. The regulations are complex and difficult to understand, thereby requiring an improbable degree of expertise to assure compliance.

2. Industry interrelationship complexities. The differences in sizes and functions of the various companies doing business in the transportation field result in inconsistencies in the processing and handling of shipments making compliance and enforcement difficult.

3. Economic Pressures. The need to make a profit may affect decisions on compliance for both the shipper and carrier. In the extreme case, cost factors may encourage misdescribing a hazardous material to avoid regulation altogether, thereby cutting expenses on classification, packaging, labeling, paperwork, and personnel.

4. Industry personnel often are unaware of regulations.

5. Lack of available training for inexperienced personnel. Often managers have received training, but personnel who are responsible for shipping have not.

6. Indifference. Due to the problems mentioned above, many subject to the regulations feel it is easier to ignore them.

Respondents to the NTSB survey indicated that trained personnel are needed to insure that the regulations are followed, particlarly due to their complexity and periodic change. This is particularly difficult for the infrequent shipper of hazardous materials who only occasionally must understand and follow the regulations. Costly delays by a carrier who believes a shipment is not in compliance can occur. This can result from actual non-compliance of a shipment or a difference in interpretation of the regulations. Material identification and classification was mentioned by several respondents in the NTSB study as very time consuming and costly. Use of specification packaging also imposes costs greater than those for regular cargo packaging. Once the regulations are understood; marking, labeling, placarding, preparing shipping papers; handling and accident reporting do not impose costs as great as those incurred with these other reponsibilities.

Many of the reasons for non-compliance identified by the NTSB study can be reduced to the cost of compliance. For example, regulation complexity requires that companies pay for the training of shipping personnel and pay to retain them after training. The expense of identifying and classifying materials is a deterrent to compliance. While the actual incremental cost of hazardous materials regulations cannot be accurately assessed in this study,* Table 5.2 presents the major areas of hazardous material regulation and a rough assessment of the relative cost of complying with each.

All of the activities labeled "high" involve important expenses although the effect on the cost of complying depends on the volume of the company's hazardous material shipments and on the specific materials shipped. For example, the added cost of training will be more important to a company with few shipments than to a company which spreads the training cost over many shipments. Also, frequent shipments help to insure that personnel are familiar with the current regulation. Similarly, material classification costs are one-time expenses which can be spread over the company's volume of shipments of the material. Obviously, the cost burden from classification is greater for materials which are not on the Hazardous Material Table and the level of compliance is expected to be lower for these materials as a result.

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*A statistical study of truck and rail rates which compared the rates for hazardous materials to the rates for similar shipments of non-hazardous material could show the carriers' assessment of the regulatory burden of the hazardous material regulations. The burden would be reflected in higher rates for hazardous materials, and the statistical analysis of the rates would measure the size and significance of the difference.

Table 5.2: Hazardous Material Regulation Activity Costs

Activity	One-time Expense	Repeated Expense	Estimated Over-all Impact on Cost
Training Personnel	x		High
Material Classification	x		High
Packaging		x	High
Marking		x	Medium
Labeling		x	Medium
Placarding		x	Medium
Shipping Papers		x	Medium
Special handling/operations		x	Medium
Spill Reporting		x	Low

The regulations on packaging of hazardous materials affect costs in two ways. First, the cost of the specification packages may be more than the cost of non-specification packages. Second, the shipper may have to stock more containers because he has to match containers with materials and thus needs a larger variety of containers and a higher total inventory to avoid stock-out.*

All of the activities rated "medium" involve relatively minor costs which must be performed for every hazardous material shipment. These activities are described in Section 2.0. Spill reporting is rated low because it is a relatively minor cost which is required only for the shipments which spill.**

*Note that exemptions (see Section 2.4.2) appear to be aimed at relieving this problem.

**Based on 117 chemicals for which production data were available from EPA's Chemicals in Commerce Information System (CICIS) and spill data which were available from HMIR:

1. Average Production = 3.27 billion pounds per chemical in 1977 (CICIS)

2. Average pounds spilled = 65.2 thousand pounds per chemical in 1977 (HMIR)

3. Average spill size = 2414 pounds in 1977 (HMIR)

So, on average there will be one spill report for every $(3.27x10^9/65.2x10^3)x2414=121.1x10^6$ pounds produced. Therefore, even with the very conservative assumptions that average shipment size is 50,000 pounds and that once produced the material is shipped only once to its final use, spill reports will be made only once for every 2422 shipping paper, marking or other repeated expense requirement $(121.1x10^6 \div 5x10^4=2422)$.

5.3 Effects of Designating New Hazardous Substances and Reportable Quantities

Under CERCLA, EPA has the responsibility for designating additional hazardous substances and the associated reportable quantities. Section 2.0 identified three categories of new designations. The first category consists of those new hazardous substances which are already on the Hazardous Material (HM) Table. The second category consists of those new hazardous substances which are not on the HM Table but which have characteristics which make them hazardous materials subject to DOT hazardous material regulation. The third category consists of new hazardous substance which were not previously regulated by DOT. These will all be ORM-E hazard class materials.

Table 5.3 shows the incremental regulation cost associated with each of these categories of newly designated hazardous substances*. Added training of shipping personnel is very minor for Categories 1 and 2, involving only the few special requirements which are unique to hazardous substances: "RQ" marking, "RQ" on shipping papers, and reporting spills to NRC. Somewhat

*Note that these costs are those which are directly imposed by DOT regulation of hazardous substances. Other costs might include insurance cost for carriers and shippers, the cost of obtaining an ICC certificate for motor carriers, and costs associated with not being able to choose any motor carrier for shippers.

Table 5.3 Incremental Costs from Hazardous Substance Designation

Activity	Category 1 (On Table)	Category 2 (Regulated but not on Table)	Category 3 (Not regulated-ORM-E)
Training Personnel	+	+	+
Material Classification	N.C.	-	+
Packaging	N.C.	N.C.	N.C
Marking	+	+	+
Labeling	N.C.	N.C.	None
Placarding	N.C.	N.C.	None
Shipping Papers	+	+	+
Special Hand-ling/Operations	N.C.	N.C.	None
Spill Reporting	+	+	+

+ Costs will be higher
- Costs will be Lower
N.C. No Change in Cost.
None the activity is not required.

more training will be required for Category 3 if the company did not ship any hazardous materials because the training must include a familiarization with the structure of DOT's hazardous material regulation.

The cost of material identification and classification remains unchanged for those newly designated substances which were already on the HM Table (Category 1) and should be easier for Category 2 because the substance will be entered onto the HM Table, thus eliminating the job of classifying it. Category 3 substances will all be found on the HM Table but they must be identified where as they were previously unregulated.

The letters "RQ" must be added to the other usual hazardous material markings and shipping papers for Categories 1 and 2. Category 3 materials require all the hazardous materials marking be added to normal non-hazardous commodity markings. Proper shipping name and material identification number are the key additions. Similarly, Category 3 materials must have the information on the shipping papers required for hazardous materials as well as the letters "RQ".

Finally, spills of Category 1 or 2 substances must be reported to NRC in addition to the previous requirement to report spills to MTB. Category 3 spill reporting changes from none required to reports to both NRC and MTB.

The incremental costs associated with designating Category 1 and 2 materials as hazardous substances appear to be minor. Of the three high cost activities; training, classification, and packaging; only minor amounts of training are required by companies not currently shipping hazardous substances. Furthermore, the classification costs should be reduced by designation for Category 2 materials.

Will these added costs affect compliance rates? The small added cost to Category 1 and 2 materials seems unlikely to affect compliance rates, although even small additions could result in small reductions in compliance. The incremental costs associated with designating Category 3 commodities as hazardous substances are more substantial. This is particularly true for companies which ship only Category 3 or unregulated commodities, because designation adds the full set of hazardous material regulations and the training costs are likely to be significant.

The reportable quantity associated with a hazardous substance affects the fraction of shipments which bear some of the incremental costs identified in Table 5.3. Marking, paperwork and spill reporting costs are required only for shipments containing at least a reportable quantity of a substance. The incremental cost of personnel training and material classification associated with hazardous substances are not, however, dependent upon the RQ level. These costs cannot be avoided by shipping a package with less than an RQ. That is, the designation of a hazardous substance carries the requirements for personnel training and material classification regardless of the RQ level associated with the substance.

Table 5.4 presents the fraction of shipments below the current RQ levels for hazardous substances.* It shows that 60% of all shipments are less than 5000 pounds. Therefore, if the RQ were set at 5000 pounds for all hazardous materials, only 40% of the shipments would be subject to the marking, shipping paper, and spill reporting costs. RQs will be assigned, however, on a substance-by-substance basis. Table 5.5 shows how two existing hazardous substances differ in their shipment size distribution. Both of these substances have an RQ of 100 pounds. The table shows that while less than 2% of the anhydrous ammonia shipments need not incur the marking, paperwork and spill reporting costs, almost 20% of the calcium hypochlorite shipments avoid these costs by being below the RQ. Further, an added 30% of the calcium hypochlorite shipments could avoid the costs if the RQ were increased to 1000 pounds. An increase in the RQ of anhydrous ammonia to 1000 pounds would affect only 0.5% of the shipments. These examples show the importance of examining the shipment size distribution of each hazardous substance in determining the costs to shippers of alternative RQ levels.

*Note that these distributions are developed from spill reports received by MTB. As a result, small shipments may be under-represented.

Table 5.4: Fraction of Shipments Below Selected Levels

Shipment Size	Fraction of Shipments in HMIR File
<1 lbs.	.001
<10 lbs.	.031
<100 lbs.	.155
<1000 lbs.	.425
<5000 lbs.	.600
<50,000 lbs.	.863

Table 5.5: Comparison of Shipment Size Distributions for Two CWA Hazardous Substances

Fraction of Shipments*

Shipment Size (lbs.)	Anhydrous Ammonia	Calcium Hypochlorite
≤1	0.0	0.0
≤10	.011	.009
≤100	.016	.191
≤1000	.021	.594
≤ 5000	.029	.831
≤50,000	.110	.982
>50,000	.890	.018

*From HMIR data, 1976-81

Will different RQ levels affect compliance? The major incremental costs associated with the designation of a hazardous substance are training shipping personnel and identifying and classifying the material. These costs are unaffected by adjustments in the RQ assigned to the substance. So, it seems unlikely that adjustments to RQ would have much affect on the costs to shippers or on their subsequent compliance. On the other hand, the burden of reporting can be decreased substantially (10-30%) by changing the RQ of a substance by an order of magnitude. This reporting burden affects the NRC as well as the carrier and, for Category 3 hazardous substances, reporting to MTB as well.

5.4. Summary

In this section we examined the limited data on non-compliance with hazardous material regulation. This data suggests high non-compliance rates, particularly with trucking regulations. Studies of the reasons for non-compliance are anecdotal but suggest that compliance involves costs which could be avoided by not complying with regulations. Of the major activities required by hazardous materials regulations, training shipping personnel, material classification, and packaging appear to affect the cost of compliance the most while reporting, because it is only required for the subset of shipments which spill, appears to place the smallest burden on shippers.

Designation of new hazardous substances will increase the cost of compliance slightly for hazardous substance which were previously hazardous materials. This increase could be expected to increase non-compliance slightly.

New hazardous substances which were not previously regulated will experience the greatest increase in cost of compliance. The shippers which did not previously ship any hazardous materials will be affected the most because the new hazardous substances will force them to become familiar with the whole structure of hazardous materials regulation. In fact, the most significant consequence of designating new hazardous substances, from the shippers point of view, is that more shippers will be affected by hazardous material regulation.

The RQ level set for a hazardous substance determines which shipments will bear incremental costs of shipping paper preparation, marking, and spill reporting, all of which are small. Because these costs are small, designation of an alternative RQ level for a hazardous substance is unlikely to influence the level of compliance or the shipment size distribution.

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APPENDIX

The objective of this Appendix is to show how the set of assumptions presented in Table 3.10 of section 3.3 are used to develop an upper bound on the probability of an incident in which two packages containing the same hazardous substance spill, when each package contains less than a reportable quantity (RQ), yet more than an RQ spills; given that an incident involving a hazardous substance has occurred. Obviously another goal of the development is to reduce the probability to a set of probabilities each of which can be estimated using the HMIR data described in 3.0. (Note that the numbered assumptions in Table 3.10 are correspondingly numbered in the following development.)

Let:

S = the set of X,A,B hazardous substances

S_X, S_A, S_B = the sub sets of X,A, or B hazardous substances

$Y \in S$ means Y is an element of S

k_1 = first spilled commodity

k_2 = second spilled commodity

t = number of packages or shipments spilled

w_1 = the weight contained in package one

w_2 = the weight contained in package two

Q_1 = the weight spilled from package one

Q_2 = the weight spilled from package two

Then, the probability of interest, $P^{(2)}$, is:

$$P^{(2)} = \frac{\sum_{Y \in S} \Pr(t=2,\ k_1=Y,\ k_2=Y,\ w_1<RQ_Y,\ w_2<RQ_Y,\ Q_1+Q_2 \geq RQ_Y \mid t \geq 1)}{\sum_{Z \in S} \Pr(k_1=Z \text{ or } k_2=Z \mid t \geq 1)}$$

Examine:

$$C(Y) = Pr(t=2,\ k_1=Y,\ k_2=Y,\ w_1<RQ_Y,\ w_2<RQ_Y,\ Q_1+Q_2\geq RQ_Y \mid t\geq 1)$$

$$= Pr(t=2,\ k_2=Y,\ w_1<RQ_Y,\ w_2<RQ_Y,\ Q_1+Q_2\geq RQ_Y \mid t\geq 1,\ k_1=Y)\ Pr(k_1=Y \mid t\geq 1)$$

$$= Pr(k_2=Y,\ w_1<RQ_Y,\ w_2<RQ_Y,\ Q_1+Q_2\geq RQ_Y \mid t=2,\ k_1=Y)$$
$$\cdot Pr(t=2 \mid t\geq 1,\ k_1=Y)\ Pr(k_1=Y \mid t\geq 1)$$

Assume that the probability of a two spill incident is independent of the material spilled. Then:

1) $Pr(t=2 \mid t\geq 1,\ k_1=Y) = Pr(t=2 \mid t\geq 1)$, and

$$C(Y) = Pr(k_2=Y,\ w_1<RQ_Y,\ w_2<RQ_Y,\ Q_1+Q_2\geq RQ_Y \mid t=2,\ k_1=Y)$$
$$\cdot Pr(t=2\ \ t\geq 1)\ Pr(k_1=Y\ \ t\geq 1)$$

$$C(Y) = Pr(w_1<RQ_Y,\ w_2<RQ_Y,\ Q_1+Q_2\geq RQ_Y \mid t=2,\ k_1=Y,\ k_2=Y)$$
$$\cdot Pr(k_2=Y \mid t=2,\ k_1=Y)\ Pr(t=2 \mid t\geq 1)\ Pr(k_1=Y \mid t\geq 1)$$

Assume that the probability that the second material spilled in a two spill incident is the same as the first material spilled is independent of the first material. Then:

2) $Pr(k_2=Y \mid t=2,\ k_1=Y) = Pr(k_2=k_1 \mid t=2)$ and

$$C(Y) = Pr(w_1<RQ_Y,\ w_2<RQ_Y,\ Q_1+Q_2\geq RQ_Y \mid t=2,\ k_1=Y,\ k_2=Y)$$
$$\cdot Pr(k_2=k_1 \mid t=2)\ Pr(t=2 \mid t\geq 1)\cdot Pr(k_1=Y \mid t\geq 1).$$

Recall that:

$$p^{(2)} = \sum_{Y \in S} \frac{C(Y)}{\sum_{Z \in S} \Pr(k_1=z \text{ or } k_2=z \quad t \geq 1)}$$

$$= \sum_{Y \quad S} [\Pr(w_1 < RQ_Y,\ w_2 < RQ_Y,\ Q_1+Q_2 \geq RQ_Y \mid t=2,\ k_1=Y,\ k_2=Y)$$

$$\cdot \Pr(k_2=k_1 \mid t=2)\ \Pr(t=2 \mid t \geq 1)\ \Pr(k_1=Y \mid t \geq 1)]$$

$$\div \sum_{Z \in S} \Pr(k_1=z \text{ or } k_2=z \mid t \geq 1)$$

This expression can be rewritten as:

$$p^{(2)} = \Pr(t=2) \mid t \geq 1)\ \Pr(k_2=k_1 \mid t=2) \cdot \sum_{Y \in S} \left(\frac{\Pr(k_1=Y \mid t \geq 1)}{\sum_{Z \in S} \Pr(R_1=z \text{ or } k_2=z \mid t \geq 1)} \right)$$

$$\cdot \Pr(w_1 < RQ_Y,\ w_2 < RQ_Y, Q_1+Q_2 \geq RQ_Y \mid t=2,\ k_1=Y,\ k_2=Y)$$

The first two terms can be moved out of the summation because they are constant, unaffected by the material.

Examine:

$$D(Y) = \frac{Pr(k_1=Y \mid t\geq 1)}{\sum_{z \in S} Pr(k_1=z \text{ or } k_2=z \mid t\geq 1)}$$

$Pr(k_1=z \text{ or } k_2=z \mid t\geq 1)$ is short for

$Pr(t=1 \text{ and } k_1=z; \text{ or } t=2 \text{ and } k_1=z; \text{ or } t=2 \text{ and } k_2=z \mid t\geq 1)$

However, since t=2 only .06 of the time that $t\geq 1$ and since $k_1=z$ some of the time when $k_2=z$, this expression can be approximated by:

$Pr(k_1=z \mid t\geq 1)$.* So,

$$D(Y) = \frac{Pr(k_1=Y \mid t\geq 1)}{\sum_{z \in S} Pr(k_1=z \ t\geq 1)} = Pr(k_1=Y \mid t\geq 1,\ Y \in S).$$

*$Pr(k_1=z \text{ or } k_2=z \mid t\geq 1)$ should also cover the situation where t=3, 4 ... , and a complete statement of this approximation would include k_3, k_4 ... = z. However, the arguments made when t=2 apply for the t=3, 4, ... cases as well.

Thus, the original probability becomes:

$$P^{(2)} = Pr(t=2 \mid t\geq 1)\ Pr(k_2=k_1 \mid t=2) \sum_{Y\in S} Pr(k_1=Y \mid t\geq 1,\ Y\in S)$$

$$\cdot Pr(w_1<RQ_Y,\ w_2<RQ_Y,\ Q_1+Q_2\geq RQ_Y \mid t=2,\ k_1=Y,\ k_2=Y)$$

Now: $S = S_X+S_A+S_B$

and: $RQ_Y = 1$ lb. for $Y\in S_X$
$RQ_Y = 10$ lbs. for $Y\in S_A$
$RQ_Y = 100$ lbs. for $Y\in S_B$

So, $P^{(2)}$ can be rewritten:

$$P^{(2)} = Pr(t=2 \mid t\geq 1)\ Pr(k_2=k_1 \mid t=2) \quad [\sum_{Y\in S_X} Pr(k_1=Y \mid t\geq 1,\ Y\in S)$$

$$\cdot Pr(w_1<1,\ w_2<1,\ Q_1+Q_2\geq 1 \mid t=2,\ k_1=Y,\ k_2=Y)$$

$$+ \sum_{Y\in S_A} Pr(k_1=Y \mid t\geq 1,\ Y\in S)\ Pr(w_1<10,\ w_2<10,\ Q_1+Q_2\geq 10 \mid t=2,\ k_1=Y,\ k_2=Y)$$

$$+ \sum_{Y\in S_B} Pr(k_1=Y \mid t\geq 1,\ Y\in S)$$

$$\cdot Pr(w_1<100,\ w_2<100_1,\ Q_1+Q_2\geq 100 \mid t=2,\ k_1=Y,\ k_2=Y)]$$

Examine the second factor in the first sum in the brackets (call it F(Y)):

$$F(Y) = Pr(w_1<1,\ w_2<1,\ Q_1+Q_2\geq 1 \mid t=2,\ k_1=Y,\ k_2=Y)$$

$$F(Y) = Pr(w_2<1,\ Q_1+Q_2\geq 1 \mid t=2,\ k_1=Y,\ k_2=Y,\ w_1<1)$$
$$\cdot Pr(w<1 \mid t=2,\ k_1=Y,\ k_2=Y)$$

Assume that the probability that the first spilled shipment contained less than a pound is independent of the material in the shipment and of whether the two spilled materials are the same. Then:

3) $$Pr(w_1<1 \mid t=2,\ k_1=Y,\ k_2=Y) = Pr(w_1<1 \mid t=2), \text{ and}$$

$$F(Y) = Pr(w_2<1,\ Q_1+Q_2\geq 1 \mid t=2,\ k_1=Y,\ k_2=Y,\ w_1<1)\ Pr(w_1<1 \mid t=2)$$

$$= Pr(Q_1+Q_2\geq 1 \mid t=2,\ k_1=Y,\ k_2=Y,\ w_1<1,\ w_2<1)$$

$$\cdot Pr(w_2<1 \mid t=2,\ k_1=Y,\ k_2=Y,\ w_1<1)\ Pr(w_1<1 \mid t=2)$$

Assume that the probability that the second spilled shipment contains less than a pound is independent of the material spilled. Then:

4) $$Pr(w_2<1 \mid t=2,\ k_1=Y,\ k_2=Y,\ w_1<1) = Pr\ (w_2<1 \mid t=2,\ k_1=k_2,\ w_1<1), \text{ and}$$

$$F(Y) = Pr(Q_1+Q_2 \geq 1 \mid t=2,\ k_1=Y,\ k_2=Y,\ w_1<1,\ w_2<1)$$

$$\cdot Pr(w_2<1 \mid t=2,\ k_1=k_2,\ w_1<1)\ Pr(w_1<1 \mid t=2)$$

Examine the first factor of F(Y):

$$G(Y) = Pr(Q_1+Q_2 \geq 1 \mid t=2,\ k_1=Y,\ k_2=Y,\ w_1<1,\ w_2<1)$$

Certainly either Q_1 or Q_2 must be larger than 1/2 pound if Q_1+Q_2 is to be larger than a pound. So:

$$G(Y) \leq H(Y) = Pr(Q_1 \geq 1/2 \text{ or } Q_2 \geq 1/2 \mid t=2,\ k_1=Y,\ k_2=Y,\ w_1<1,\ w_2<1).$$

Assume that the probability that either spill is less than 1/2 pound is independent of the material spilled or the fact that the same material spilled from both packages. Then:

5) $H(Y) = Pr(Q_1 \geq 1/2 \text{ or } Q_2 \geq 1/2 \mid t=2,\ w_1<1,\ w_2<1).$

If we assume either that Q_1 is independent of Q_2 or that if not independent that they are positively associated* then we can estimate an upper bound on H(Y):

$$H(Y) \leq 1 - (Pr(Q \leq 1/2 \mid t=2,\ w<1))^2.$$

*By positively associated we mean that larger values of Q_1 are on the average associated with larger values of Q_2 and similarly smaller values of Q_1 are associated with smaller values of Q_2. By assuming that Q_1 and Q_2 are either positively associated or independent we are assuming that they are not negatively associated. That is we are assuming that smaller values of Q_1 are not on the average associated with larger values of Q_2.

So,

$$G(Y) \leq 1 - (Pr(Q \leq 1/2 \mid t=2,\ w<1))^2$$ and an upper bound on F(Y)

is:

$$F(Y) = [1 - (Pr(Q \leq 1/2 \mid t=2,\ w<1))^2]$$

$$\cdot Pr(w_2<1 \mid t=2,\ k_1=k_2,\ w_1<1)\ Pr(w_1<1 \mid t=2)$$

Recall that the first summation in the last expression for $P^{(2)}$ is:

$$J(Y) = \sum_{Y \in S_X} Pr(k_1=Y \mid t \geq 1,\ Y \in S)\ F(Y).$$

Substituting in the upper bound on F(Y) yields:

$$J(Y) = \sum_{Y \in S_X} Pr(k_1=Y \mid t \geq 1\ Y \in S)\ Pr(w_2<1 \mid t=2,\ k_1=k_2,\ w_1<1)$$

$$\cdot Pr(w_1<1 \mid t=2)\ (1-(Pr(Q \leq 1/2 \mid t=2,\ w<1))^2).$$

Because only the first factor depends on the material, this expression can be rewritten:

$$J(Y) = Pr(w_2<1 \mid t=2,\ k_1=k_2,\ w_1<1)\ Pr(w_1<1 \mid t=2)(1-(Pr(Q \leq 1/2 \mid t=2,\ w<1))^2)$$

$$\cdot \left[\sum_{Y \in S_X} Pr(k_1=Y \mid t \geq 1,\ Y \in S)\right]$$

Now the final summation in J(Y) can be restated:

$$\sum_{Y\in S_X} Pr(k_1=Y \mid t\geq 1, Y\in S) = Pr(k_1\in S_X \mid t\geq 1,\ k_1\in S)$$

and

$$J(Y) = Pr(w_2<1 \mid t=2,\ k_1=k_2,\ w_1<1)\ Pr(w_1<1 \mid t=2)$$

$$\cdot(1-(Pr(Q\leq 1/2 \mid t=2,\ w<1))^2)\ Pr(k_1\in S_X \mid t\geq 1,\ k_1\in S)$$

Similar logic can be used to develop upper bounds on the other two summations in the final expression for $P^{(2)}$. The result is:

$$P^{(2)} = Pr(t=2 \mid t\geq 1)\ Pr(k_2=k_1 \mid t=2)$$

$$\cdot[Pr(k_1\in S_X \mid t\geq 1,\ k_1\in S)\ Pr(w_1<1 \mid t=2)$$

$$\cdot Pr(w_2<1 \mid t=2,\ k_1=k_2,\ w_1<1)(1-(Pr(Q\leq 1/2 \mid t=2,\ w<1))^2)$$

$$+\ Pr(k_1\in S_A \mid t\geq 1,\ k_1\in S)\ Pr(w_1<10 \mid t=2)$$

$$\cdot Pr(w_2<10 \mid t=2,\ k_1=k_2,\ w_1<10)(1-(Pr(Q\leq 5 \mid t=2,\ w<10))^2)$$

$$+\ Pr(k_1\in S_B \mid t\geq 1,\ k_1\in S)\ Pr(w_1<100 \mid t=2)$$

$$\cdot Pr(w_2<100 \mid t=2,\ k_1=k_2,\ w_1<100)(1-(Pr(Q\leq 50 \mid t=2,\ w<100))^2)].$$