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Hazardous Materials Car Placement In A Train Consist

Office of Research and Development
Washington, DC 20590

Volume I
Review and Analysis

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16. Abstract

In response to major derailments involving hazardous materials cars, the Federal Railroad Administration (FRA) initiated this review of the consequences of hazardous materials car placement in a train consist. The review and analysis consisted of six task items: (1) review of accident trends and regulations, (2) an analysis of hazardous materials compatibility, (3) railroad operational constraints, (4) a cost/benefit analysis, (5) recommendations, and (6) preparation of a final report.

A review of the 1982-1985 Railroad Accident/Incident Reporting System (RAIRS) data showed the rear quarter to be statistically the "safest" location in a mainline freight train. Analysis confirmed that the longer the train, or the higher the speed, the more cars derailed on the average. Also, the top 101 hazardous commodities (by volume movement) plus fuming nitric acid were analyzed for chemical incompatibility, a total of 5,151 binary combinations. Of these, 1,210 combinations were judged incompatible. Combinations involving non-oxidizing mineral acids (ASTM Chemical Reactivity Group 1), oxidizing mineral acids (Group 2) and caustics (Group 10) dominate the list of incompatible chemicals. Consequence-based and risk-based rankings were established. Calculations established a post-derailment separation distance of 40 meters minimum to prevent mixing of incompatible chemicals. This can be accomplished by a conservative (worst-case) in-train separation by 30 cars for incompatible hazmat cargos, although a 15-car separation may accomplish this for most accident scenarios. It was noted that mixing of hazmat materials was not cited in any NTSB accident report as a specific problem.

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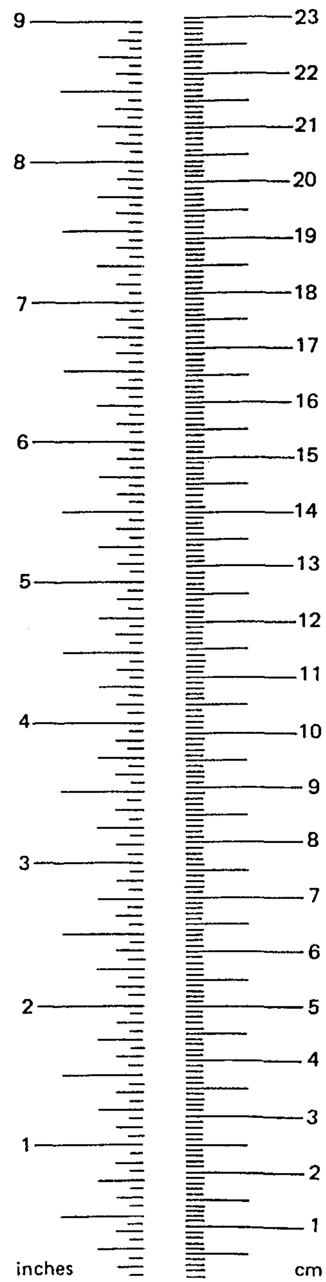
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

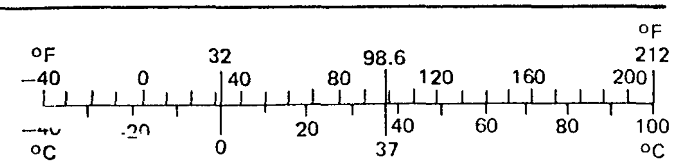
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

Task Order No. 6 (Hazardous Materials Car Placement in a Train Consist) was conducted under Battelle's contract with the Federal Railroad Administration (FRA) relative to Quick Response Safety Research of Railroad Vehicles, Track and Components (Contract No. DTFR53-86-C-00006). Its objective was to identify and evaluate current procedures for the placement of hazardous materials cars in a train consist, and to identify improvements that could be made to reduce the risk of derailment and/or the release of hazardous materials and their commingling should release during derailment occur. In large part, this work was prompted by recent major derailments in Bloomfield and Confluence, Pennsylvania. In consequence, the FRA was requested to review the in-train placement of tank cars carrying hazardous materials. It was also proposed that such cars might be spread out along train consists instead of coupling them together in groups.

The task order required a review of accident statistics, accident reports, regulations, hazardous materials compatibility, and train make-up procedures to determine the issues to be addressed in cost/benefit analysis for placement of hazmat cars in a train consist. Recommendations were to be made based on the analysis then conducted. Task Order No. 6 was structured as six individual Task Items as follows:

- Task Item 1--Review of Accident Trends and Regulations
- Task Item 2--Hazardous Materials Compatibility
- Task Item 3--Operational Constraints
- Task Item 4--Cost/Benefit Analysis
- Task Item 5--Recommendations
- Task Item 6--Final Report.

This document is the final report and is, therefore, the results of Task Item No. 6. It details the analyses and the results obtained under Task Items 1 through 5. These are contained in the following sections and are presented on a per task item basis.

2.0 TASK ITEM 1--REVIEW OF ACCIDENT TRENDS AND REGULATION

Task Item 1 was the first of six items which comprise Task Order No. 6. It consisted of three interrelated activities as follows:

1-1. Review the 1979 draft report by the Transportation Systems Center (TSC) [Ref. 1], which is concerned with the in-train position of derailed rail cars, along with current accident statistics to determine if the conclusions in the TSC report are still valid. Also, give specific attention to the train dynamics issues related to the derailment process, the resulting severity, and the dispersion of cars in accidents.

1-2. Review past accidents involving hazardous materials to determine if any mixing of released commodities occurred. And, whether or not such mixing worsened the accident situations in terms of fire or explosion, evacuation, area contamination, and clean-up efforts.

1-3. Review the current U.S. Department of Transportation (DOT) regulations (49 CFR 174.81 and Subpart D) and those of the Canadian Transport Commission (Subpart E, 74.589) concerning the placement within a train of cars carrying hazardous commodities. And, perform a brief comparison of the two sets of regulations to identify relative coverage and areas of difference.

These activities were conducted concurrently and, to a large extent, in an integrated manner. The work and results associated with each are described below.

2.1 Comparison with TSC Report Findings

The findings and associated analysis activities described in the TSC report [Ref. 1] are related to railroad accident/derailment data for calendar years 1975, 1976, and 1977. Their primary data sources were the FRA/DOT Accident/Incident Bulletins[1] and, especially, the Railroad Accident/Incident Reporting System (RAIRS) data tapes for these three years. The "Preface" of the TSC report stated that:

> "The purpose of this work, which was initiated in April 1978, was to further explore the idea that most derailments involve cars placed towards the front of a train. If this apparent situation could be verified, then procedures for increasing the safety in transporting various "critical" cargos might be achieved by means of strategically positioning them in the rear section of the train to reduce their risk of derailment and consequent damage."

It was also stated therein that:

> "The actuarial existence of this phenomenon was clearly demonstrated and has prompted the need to develop additional details concerning the costs, benefits, and operational impacts of implementing any resulting procedures."

This conclusion was based upon statistical data contained in the body of the report, and was reemphasized in the "Executive Summary" where it was stated that:

> "Based on more than 22,000 actual train derailments, a clear pattern is evident, showing that the risk of derailment and subsequent damage has been significantly higher in the forward section of a train than it is in the rear third or rear quarter of a train."

The TSC car placement analysis work primarily concentrated on determining and analyzing the in-train location of all derailed units (not merely cars carrying hazardous materials) within all reportable train accidents[2] classified as derailments for each of the three subject

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1 Bulletin Nos. 145 (CY 1975), 146 (CY 1976), and 147 (CY 1977).

2 The reporting damage cost threshold that determines which accidents must be reported is adjusted on a biennial basis to reflect the effect of inflation on costs. Damage covers railroad on-track equipment, signals, track or track structures, and roadbed. To better represent annual trends, the data reported in the FRA Accident/Incident Bulletins for the second year of a threshold

calendar years. Analyses were conducted on the basis of various Type of Track (i.e. main, yard, siding, industry) and Primary Cause (i.e. track, equipment, human factors, and "miscellaneous"). However, their basic analysis work and primary findings were related to summary analyses which included all derailments regardless of cause or type of track involved.

TSC utilized all accidents/incidents which were coded as derailments.[3] These were then examined to remove "bad data", which were defined as: (1) accidents where the total number of cars derailed was zero; (2) accidents which were reported more than once, and (3) accidents where the train length was less than the value of the "First involved position in train", plus the "total number of units derailed", minus 1.[4] The remaining derailments (a total of 22,297 for the three years) were then subjected to analysis to determine the in-train position of each derailed unit (i.e. locomotives, loaded cars, empty cars, and cabooses). The derailments for each of the three years were compiled into twenty-one groupings by train length. The sets of groupings were then combined and further analysis conducted to determine what numbers and percentages of the total number of cars derailed occurred in each third (front, middle, rear) and each quarter, (first, second, third, fourth) of the trains. This was done for each year and then summarized. The essential

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change is now adjusted by limiting the count of accidents to those resulting in reportable damage of a greater dollar value. The resulting threshold values are: 1975-$1,750, 1976-$1,750, 1977-$2,300, 1978-$2,600, 1979-$2,900, 1980-$3,200, 1981-$3,700, 1982-$4,100, 1983-$4,500, 1984-$4,700, 1985-$4,900, and 1986-$5,050. It is most likely that the damage cost of even a "minor" derailment would exceed those thresholds, and so be reported.

3 The FRA Accident/Incident Bulletins define Derailment as follows: "a derailment occurs when one or more than one unit of rolling stock equipment leaves the rails during train operations for a cause other than collision, explosion, or fire." Derailments are identified on the DOT/FRA Rail Equipment Accident/Incident Report forms (Form FRA F 6180-54 12/74) by the insertion of a "1" in the code box for Item 7 - Type of Accident/Incident. A copy of this form is provided here in Appendix A.

4 While not explicitly stated in the TSC report, it appears that the "first involved position in train" was considered as the frontmost derailed unit and all other derailed units were considered to have followed immediately in position behind that unit.

numerical findings resulting from TSC's analysis work are repeated here in Table 1.

To provide a direct basis for comparison with TSC's findings, Battelle conducted similar analyses as those of TSC relative to the RAIRS data tapes for calendar years 1982, 1983, 1984, and 1985. Likewise, the FRA Accident/Incident Bulletins for these years were utilized.[5] The essential findings resulting from this work are presented in Table 2, and details of the analysis results are contained in Appendix B. Before addressing any comparison between the two sets of findings, it is important to note the similarities and differences between the two sets of derailment data and associated analyses. In summary, these are:

1. TSC utilized the FRA accident/incident data for calendar years 1975, 1976, and 1977; Battelle utilized the data for calendar years 1982, 1983, 1984, 1985.

2. TSC utilized all accidents/incidents coded as "derailments". After the "bad data" entries were removed (see previous discussion), a total of 22,297 derailments, for the three years, remained. Battelle utilized a lesser set of derailments within the total possible. Only derailments which occurred on "main" (Code 1) track and were related to "freight train" or "mixed train" type of equipment (Codes 1 and 3) were selected. A total of 6,425 derailments were extracted from the RAIRS data tapes for the four years. The "bad data" were then removed. This was defined as accidents where:

   - the total number of cars derailed was zero,
   - the total number of derailed units exceeded the length of the train,
   - no position was given for the first car involved or the causing car, or
   - the position of the first car involved was beyond the end of the train.

   A spot check for accidents reported more than once did not uncover any, so it was assumed that this was a negligible item. The result was 5,562 derailments for the four-year period.

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5 Bulletins Nos. 151 (CY 1982), 152 (CY 1983), 153 (CY 1984), and 154 (CY 1985).

TABLE 1. SUMMARY OF RESULTS FROM DOT/TSC ANALYSIS OF RAILROAD ACCIDENT/INCIDENT (RAIRS) DATA FOR CALENDAR YEARS 1975 THROUGH 1977

PLACEMENT OF HAZARDOUS MATERIALS CARS IN TRAIN CONSISTS
ANALYSIS OF DOT/FRA ACCIDENT/INCIDENT (RAIRS) DATA.
CALENDAR YEAR 1975 THROUGH 1977 (DOT/TSC ANALYSIS)
"UNITS" DEFINED AS LOCOMOTIVES + CARS + CABOOSE

NUMBER OF DERAILMENTS IN DATA FILE	=	22297
NUMBER OF DERAILMENTS USED IN ANALYSIS	=	22297
NUMBER OF TIMES FIRST UNIT FIRST INVOLVED	=	2502
TOTAL NUMBER OF UNITS IN CONSISTS	=	1465003
AVERAGE LENGTH OF TRAIN	=	65
TOTAL NUMBER OF DERAILED UNITS	=	126656
AVERAGE DERAILED UNITS PER TRAIN	=	5.7
TOTAL NUMBER OF HAZ MAT CARS IN CONSISTS	=	12475
HAZ MAT CARS DAMAGED IN DERAILMENTS	=	2822
HAZ MAT CARS RELEASING IN DERAILMENTS	=	470
TOTAL NUMBER OF PEOPLE EVACUATED	=	36969

ANALYSIS BY THIRDS --

TRAIN 3RD	FIRST UNIT INVOLVED	PER CENT	CAUSING UNIT	TOTAL DERAILED	PER CENT
1	10311	46.2	0	48981	38.7
2	6657	29.9	0	45891	36.2
3	5329	23.9	0	31784	25.1

ANALYSIS BY QUARTERS --

TRAIN 4TH	FIRST UNIT INVOLVED	PER CENT	CAUSING UNIT	TOTAL DERAILED	PER CENT
1	8716	39.1	0	38128	30.1
2	5282	23.7	0	37436	29.6
3	4603	20.6	0	29773	23.5
4	3696	16.6	0	21319	16.8

Note: From Section 3, Findings (pp 7-9) of Ref. 1

TABLE 2. SUMMARY OF RESULTS FROM BATTELLE ANALYSIS OF RAILROAD ACCIDENT/INCIDENT (RAIRS) DATA FOR CALENDAR YEARS 1982 THROUGH 1985

*****PLACEMENT OF HAZARDOUS MATERIALS CARS IN TRAIN CONSISTS*****
ANALYSIS OF DOT/FRA ACCIDENT/INCIDENT (RAIRS) DATA,
CALENDAR YEAR 1982 THROUGH 1985 (BATTELLE ANALYSIS)
DERAILMENTS OF FREIGHT OR MIXED TRAINS, MAINLINE TRACK ONLY
"UNITS" DEFINED AS LOCOMOTIVES + CARS + CABOOSE

NUMBER OF DERAILMENTS IN DATA FILE	=	6425
NUMBER OF DERAILMENTS USED IN ANALYSIS	=	5562
NUMBER OF TIMES FIRST UNIT FIRST INVOLVED	=	489
TOTAL NUMBER OF UNITS IN CONSISTS	=	451220
AVERAGE LENGTH OF TRAIN	=	81
TOTAL NUMBER OF DERAILED UNITS	=	44823
AVERAGE DERAILED UNITS PER TRAIN	=	8.1
TOTAL NUMBER OF HAZ MAT CARS IN CONSISTS	=	4691
HAZ MAT CARS DAMAGED IN DERAILMENTS	=	1223
HAZ MAT CARS RELEASING IN DERAILMENTS	=	289
TOTAL NUMBER OF PEOPLE EVACUATED	=	23259

ANALYSIS BY THIRDS --

TRAIN 3RD	FIRST UNIT INVOLVED	PER CENT	CAUSING UNIT	TOTAL DERAILED	PER CENT
1	2163	39.7	555	14947	33.6
2	1767	32.4	548	16878	37.9
3	1521	27.9	389	12676	28.5

ANALYSIS BY QUARTERS --

TRAIN 4TH	FIRST UNIT INVOLVED	PER CENT	CAUSING UNIT	TOTAL DERAILED	PER CENT
1	1690	31.0	409	10945	24.6
2	1357	24.9	431	12569	28.2
3	1326	24.3	378	12147	27.3
4	1078	19.8	274	8840	19.9

Note: Train Segment Analysis Ignores Short Trains (< 11 Units), Consisting of 111 Derailed Trains, 812 Units Total, and 322 Derailed Units in the Consists

3. TSC distributed the number of derailed units, starting with the position of the "first involved" unit, rearward in a consecutive manner.[6] If the end of the train was reached before the remaining number of derailed units reached zero, the item was declared as "bad data". Battelle distributed derailed units similarly, except when the end of the train was reached the remaining derailed units were distributed forward from the position of the "first involved" unit. Only if the number of derailed units exceeded the total train length was the item declared to be "bad data".

4. In determining the overall numbers and percentages of derailed units in each third and quarter segment of the trains involved, TSC utilized their entire data base of 22,297 derailments. Battelle further reduced its data base of 5,562 derailments by removing the 111 derailments associated with "short trains" (10 or less locomotives or cars). A final data base of 5,451 derailments resulted for four years.

Battelle considers that its data base, which is considerably more restricted than that used by TSC, is more in keeping with the thrust of the task now under consideration. That is, to identify opportunities for reducing the number and severity of hazardous materials car derailments by the selective placement of such cars within trains. The primary area of opportunity is, of course, the mainline transport for such cars. While there are large numbers of derailments in non-mainline situations, and these can involve hazmat cars and release of their contents, they offer relatively little opportunity for employing significant hazmat car placement strategies.

It can be expected that, except for the consists on assembly tracks in classification yards, and associated inbound and outbound trains (all of which, if new hazmat car placement rules are enacted, would contain suitably placed hazmat cars), "trains" in yards and on most

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6 The positions of derailed cars are not explicitly given in the RAIRS data; rather, they must be estimated. Both TSC and Battelle assumed that the "first car involved" was derailed and all other derailed cars were sequential in placement. While in fact, this is commonly the case, there are known instances where the units derailed are not consecutive, but occur in two or more groupings separated by non-derailed unit.

sidings would be relatively short cuts of cars.[7] Relatively long (i.e. greater than 10 units) mainline train operations do provide such opportunities however; and, in general, the longer the better the opportunity. Note that the average length of trains in Battelle's data base is 81 units, versus 65 in TSC's data base.

It is recognized that there appears to be considerable difference in the TSC and Battelle derailment data sets: the former containing 22,297 derailments for three calendar years, and the latter containing only 5,562 derailments for four calendar years. Even realizing that the Battelle set is mainline derailments only, the numerical difference might seem unreasonable. However, close agreement can be shown. Analysis details in the TSC report provided the following:[8]

1. CY 1975 had 6,229 derailments in its group, with 435,174 total units in these trains, of which 36,817 units derailed. Of these, 3,507 derailments were on mainline track, with 284,022 total units and 25,415 derailed units.

2. CY 1976 had 7,886 derailments in its group, with 510,494 total units in these trains, of which 43,635 units derailed. Of these, 4,100 derailments were on mainline track, with 317,654 total units and 28,342 derailed units.

3. CY 1977 had 8,182 derailments in its group with 519,335 total units in these trains, of which 46,204 units derailed. Of these, 4,008 derailments were on mainline track, with 304,390 total units and 28,881 derailed units.

Summation of these data shows that mainline derailments totaled 11,615, which is 52.09-percent of the 22,297 total derailments in the summary group. A similar exercise was done for the calendar years used for Battelle's derailment data base. However, here, data from the

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7 §174.83-Switching of Cars Containing Hazardous Materials within Subpart D-Handling of Placarded Cars (49 CFR), presently lists some placement restrictions, but these are primarily directed toward separating selected hazmat cars from locomotives.

8 Exhibit 4 - Annual summaries of derailed trains and cars for five primary causes, subdivided by location.

associated FRA Accident/Incident Bulletins were used.[9] The number of derailments listed for calendar years 1982, 1983, 1984, and 1985 were 3,383, 3,004, 2,915, and 2,495, respectively. These total to 11,797. The Battelle mainline derailment data base totals 5,562 (including the 111 "short trains" which were later deleted), which is 47.14 percent of the total. This value is in good agreement with the 52.09 percent associated with the TSC derailment data, especially in light of the track improvements completed since 1977, which can be expected to have a favorable impact on the number of mainline derailments since that time.

By comparing TSC and Battelle findings in Tables 1 and 2, it can be seen that the risk of derailment is significantly less in the rear third or rear quarter of a train. While the last section (either third or quarter) is still shown to be the "safest" relative to the possibility of car derailment, this condition does not degrade progressively as more forward sections are considered. Rather, Battelle's results show the first section to be the next safest locale, and the middle section(s) the worst. Further, the four-section analysis indicates that, except for the "safer" fourth quarter, there is little difference in the relative safety of the first three quarters. To a lesser extent, this finding also holds for the first two thirds of a three section train. In consequence, it would appear that for mainline track operations, any placement strategy for hazmat cars would need to concentrate on the rear third or quarter of the trains. Without further detailed analysis, it can only be assumed that the difference in the TSC and Battelle findings is primarily the consequence of TSC utilizing derailments on all types of track, and Battelle using those on mainline track only, rather than an actual change in derailment patterns over the years.

TSC conducted some review and analysis specifically directed toward accidents involving trains transporting hazardous materials. Their summary of such accidents for calendar years 1975, 1976, and 1977 is presented here in Table 3. Battelle prepared a similar summary for calendar years 1983, 1984, and 1985 in Table 4. Both summaries are

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9 Table S12A (Total Accidents/Incidents by Occurrence) in the Bulletin for CY 1982, and Table 16 (Total Accidents/Incidents by Occurrence) in the Bulletins for CYs 1983, 1984, and 1985.

TABLE 3. SUMMARY OF ACCIDENTS INVOLVING TRAINS TRANSPORTING HAZARDOUS MATERIALS (CYs 1975, 1976, AND 1977)*

YEAR	CONSISTS IN HAZMAT ACCIDENTS	TOTAL CARS IN CONSIST	TOTAL CARS CONTAINING HAZMAT	TOTAL CARS DAMAGED W/HAZMAT	TOTAL CARS RELEASING HAZMAT	PEOPLE EVACUATED	DOLLAR DAMAGES TO EQUIPMENT	REMARKS
1975	690	51,847	5,280	903	131	3,495	$24,484,509	TOTAL for all consists
		75.1	7.7	1.31	0.19	5.07	$35,485	AVG./CONSIST
1976	768	52,702	3,347	847	166	19,369	$27,068,453	TOTAL for all consists
		68.06	4.4	1.10	0.22	25.22	$35,245	AVG./CONSIST
1977	864	60,838	3,848	1,072	173	14,105	$36,406,399	TOTAL for all consists
		63.1	4.5	1.24	0.20	16.33	$42,137	AVG./CONSIST
TOTAL	2,322	165,387	12,475	2,822	470	36,969	$87,959,361	

$\frac{690}{8{,}041 \text{ ACC.s}}$ = 8.6% of total train accidents involved hazmat. (1975)

$\frac{768}{10{,}248 \text{ ACC.s}}$ = 7.5% of total train accidents involved hazmat. (1976)

$\frac{864}{10{,}362 \text{ ACC.s}}$ = 8.3% of total train accidents involved hazmat. (1977)

*Extracted from Table 2-1 (p.6) of the TSC Report

TABLE 4. SUMMARY OF ACCIDENTS INVOLVING TRAINS TRANSPORTING HAZARDOUS MATERIALS (CYs 1983, 1984, AND 1985)

YEAR	CONSISTS IN HAZMAT ACCIDENTS	TOTAL CARS IN CONSIST	TOTAL CARS CONTAINING HAZMAT	TOTAL CARS DAMAGED W/HAZMAT	TOTAL CARS RELEASING HAZMAT	PEOPLE EVACUATED	DOLLAR DAMAGES TO EQUIPMENT	REMARKS
1983	431	28,872	2,456	543	62	3,500	$32,220,676	TOTAL for all consists
		70.0	5.7	1.26	0.14	8.12	$74,758	AVG./CONSIST
1984	443	30,384	2,826	581	100	4,446	$28,535,990	TOTAL for all consists
		68.6	6.4	1.31	0.23	10.04	$64,415	AVG./CONSIST
1985	431	29,362	2,310	647	109	11,879	$33,632,216	TOTAL for all consists
		68.1	5.5	1.50	0.25	27.56	$78,033	AVG./CONSIST
TOTAL	1,305	88,618	7,592	1,771	271	19,825	$94,388,882	

$\frac{431}{3{,}906 \text{ ACC.s}}$ = 11.0% of total train accidents involved hazmat. (1983)

$\frac{443}{3{,}900 \text{ ACC.s}}$ = 11.4% of total train accidents involved hazmat. (1984)

$\frac{431}{3{,}430 \text{ ACC.s}}$ = 12.6% of total train accidents involved hazmat. (1985)

based upon statistics contained in the corresponding FRA Accident/ Incident Bulletins. In each, data from three consecutive calendar years are presented; these data cover all types of accidents (derailments, collisions, rail-highway crossing, etc.). However, the majority of the "consists in hazmat accidents" are associated with derailments. Of the 1,305 such consists cited in Table 4, 77 percent (i.e. 1,003) were classified as derailments.

The most significant differences in the two tables relate to the overall numbers of hazmat accidents. There was a decrease in the number of consists in such accidents during the most recent three-year period, and an increase in the percent of total train accidents involving such consists. It can be concluded that, while there has been a decrease in both the total number of accidents, and in accidents involving hazmat carrying trains[10], a larger percentage of trains now carry hazmat. It is difficult to compare data on "people evacuated" and "dollar damages to equipment" since these are, in part, dependent upon the nature of the hazmat involved and released, and the locales where such occur.

TSC conducted a statistical analysis of accidents of hazardous material trains for calendar year 1975 only. This work included three- and four-section analyses relative to both "damaged" hazmat cars and "releasing" hazmat cars in derailed trains. Battelle did not perform a similar analysis as it was felt this would not provide further enlightenment relative to the identification of locations within trains which were less subject to derailment. There appears to be no evidence that cars carrying hazardous materials are somehow more, or less, inherently subject to derailment. It is recognized that the majority of hazmat cars are tank cars; however, hazardous commodities are transported in other types of cars as well.[11]

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10 Other data indicate that there has been a dramatic decrease in both these areas since CY 1981.

11 It appears that tank cars are of primary interest in Task Order No. 6. Task Item 2 - Hazardous Materials Compatibility is concerned with the top 100 hazardous materials on an AAR-supplied listing of the top 125 hazmat movements by tank car volume in 1986.

2.2 Review of Dynamics of Derailment

A review was conducted of available literature and published reports contained in Battelle's Transportation Library pertinent to the causes and dynamics of derailment. The DOT/FRA RRIS Railroad Research Bulletins through Autumn 1981 were utilized to assist in this review. Two aspects of derailment in particular were examined in this review: first, derailment as a function of position in the train consist; and second, the attitude and proximity of derailed cars following the derailment.

The increase in train lengths, car sizes and loadings during the 1960s, along with the prevailing economic climate and deferred maintenance to track, led to a sharply increasing incidence of train derailments in the early 1970s. As a result, the AAR-FRA-RPI-TDA Track-Train Dynamics Program[12] was undertaken to study and define the dynamic interactions of a train consist with track as affected by operating conditions and practices. This on-going program has done much to improve industry understanding of track strength and performance needs, train makeup and handling practices, and the basic causes for train derailments. For example, many of the derailments in the 1970s were the combined result of high lateral loads in curving track under 6-axle locomotive units, misuse of dynamic braking, and reduced track strength resulting in track shift or rail rollover. As a result of the Track-Train Dynamics Program, these types of derailment involving the front portion of the train are not as common in the 1980s as in prior decades.

An extensive review of the effects of size, weight and length of freight cars on the safety and efficiency of U.S. rail transportation was sponsored by DOT/FRA in the late 1970s [Ref. 2]. The study included reviews of freight car fleet characteristics, car safety records, and derailment causes. While derailment dynamics in the context of car location in consist was not addressed, per se, the preferred location of loaded versus empty cars was mentioned:

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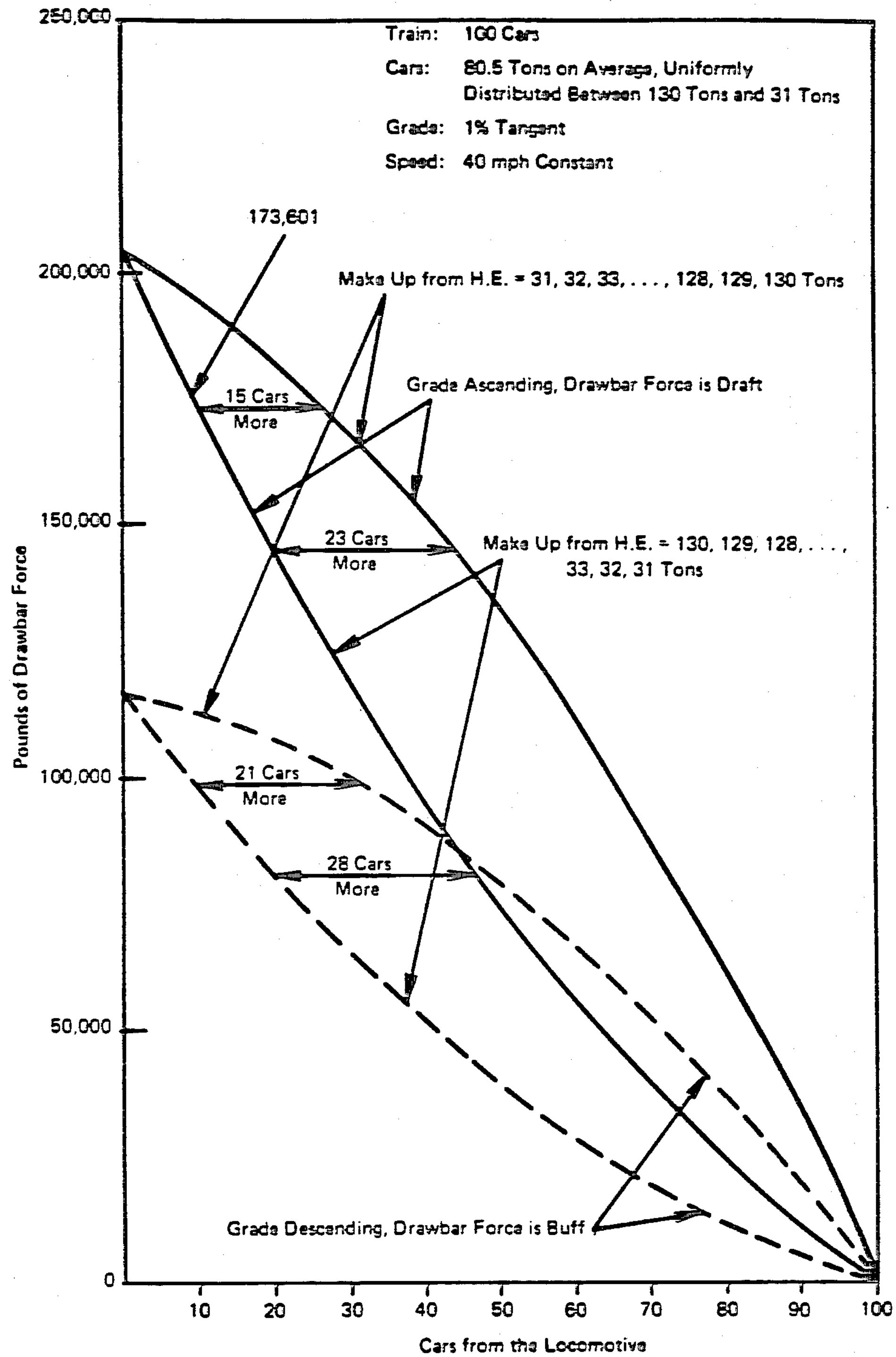
12 AAR = Association of American Railroads; FRA = Federal Railroad Administration; RPI = Railway Progress Institute; TDA = Transportation Development Agency, Railway Association of Canada.

> "When a train contains both loaded and empty cars, it is preferable to place the loaded cars at the front of the train. Loaded cars usually experience the same braking force as empty cars and, because of their larger weight, decelerate at a lower rate than empty cars. If they were placed toward the end of the train, they would push against the light, empty cars at the front of the train, creating high buff forces and L/V ratios."

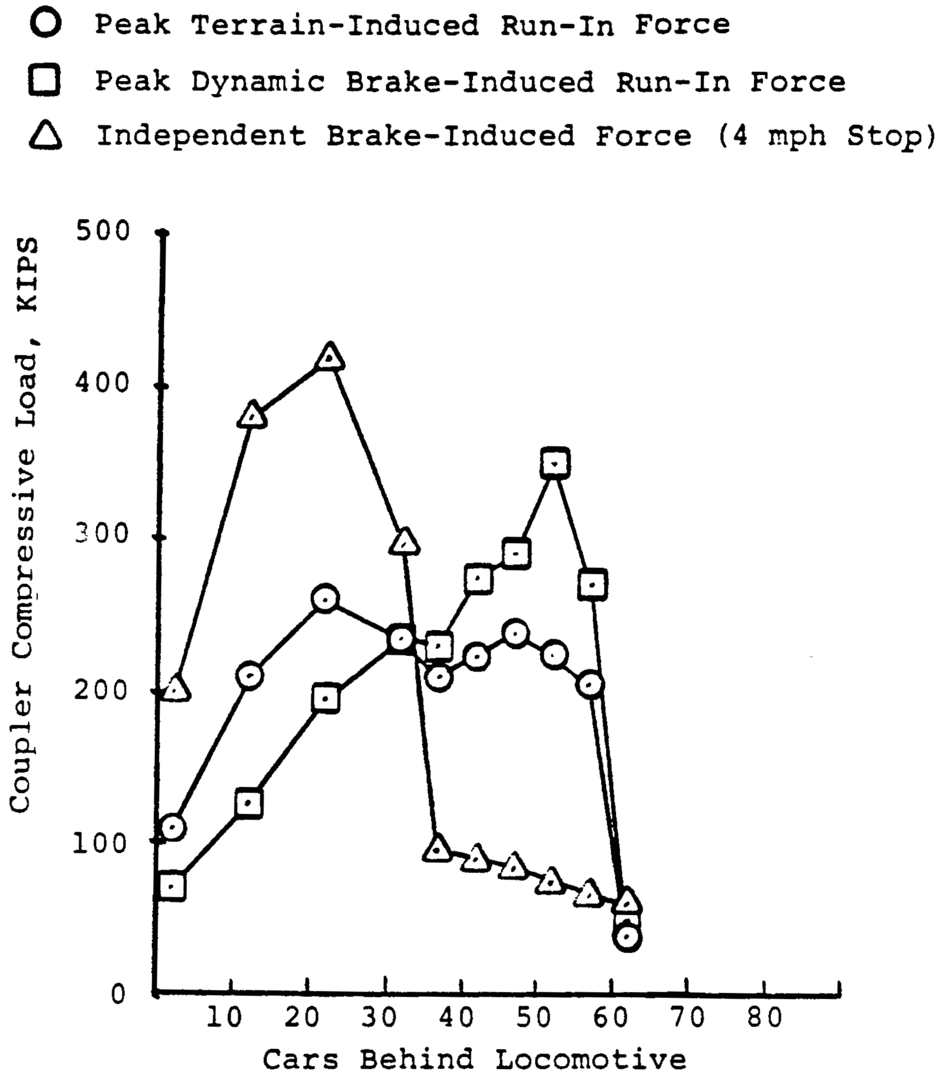
This effect is shown by the theoretical drawbar force curves in Figure 1 for increasing versus decreasing car weight distributions in the consist. One contributing factor to derailment is, of course, the transient longitudinal "train action" forces. Several derailments of the Tropicana Unit Train in 1970 resulted in a test program [Ref. 3] utilizing instrumented couplers spaced throughout the train consist to measured train action (run-in, run-out) forces. The train consisted of two locomotive units, an instrumentation car, 60 loaded 100-ton boxcars with end-of-car cushioning devices, and a caboose. Examples of peak measured run-in (derailment-inducing) forces by location in train are shown in Figure 2. Terrain-induced run-in force peaks are shown to be distributed fairly uniformly across the rear two-thirds of the train. Dynamic brake-induced force peaks tend to rise to a maximum in the rear one-third of the train as the run-in speed differential between cars propagates rearward. The worst measured case occurred with use of the independent (locomotive) brake in a 4-mph stop at a fueling station, where the highest coupler loads were measured in the first third of the train. Tests were also conducted with a 157-car phosphate train (15,626 gross tons) with conventional draft gear. Here the highest measured run-in forces occurred just ahead of the test car and caboose:

Location (cars Ahead)	Run-in Force (kips)
1	400
5	335
10	265
15	250



Source: Track Train Dynamics

FIGURE 1. DRAFT GEAR LONGITUDINAL FORCE BETWEEN CARS BY POSITION OF CARS IN TRAIN CONSIST: THE EFFECTS OF CAR WEIGHT DISTRIBUTION



Source: R.G. Powers, J.G. Stephenson, "Trainaction Measurements in the Tropicana Unit Train", ASME Paper No. 73-WA/RT-9, November 1973.

FIGURE 2. EXAMPLES OF COUPLER LONGITUDINAL (RUN-IN) FORCES AT DIFFERENT LOCATIONS IN UNIT TRAIN OPERATIONS

Derailments caused by poor train handling procedures on a heavy haul railroad in Australia were reported by Fahey, et al [Ref. 4]. Seven major derailments on the Hamersley Iron Railway in the early 1970s were investigated. These derailments had the following common aspects:

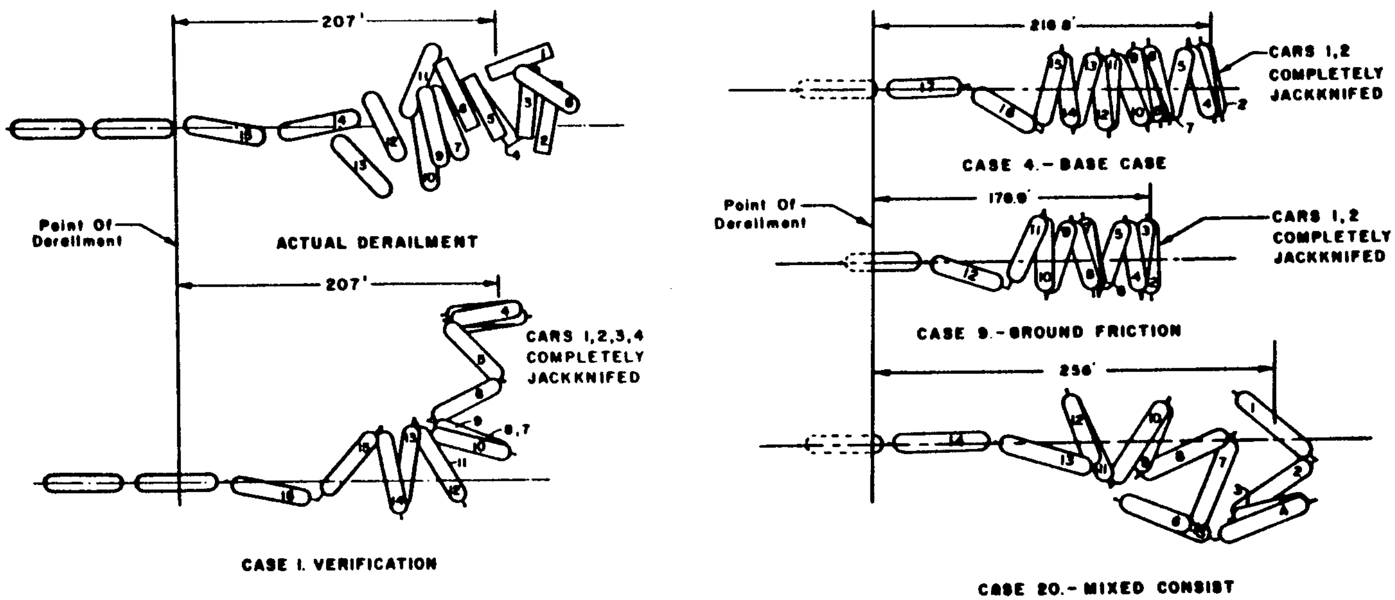
- Train speed of 55-65 km/h (34-40 mph),
- Derailment occurred at (or shortly after) a "sag",
- Four derailments occurred in the middle third of the train, 70-80 cars from the rear (train consists were two locomotive units, 135 cars; one train had three units, 170 cars),
- Derailments followed a change of operating mode (power to dynamic braking, or vice versa).

A program to educate train drivers in the proper handling of these heavy trains reduced the derailment and train pull-apart problems to manageable levels.

An analytical study entitled "Dynamic Analysis of Train Derailments" was conducted by Yang, et al [Ref. 5], of Pullman-Standard in the early 1970s. A computer simulation in the horizontal plane was generated and verified by comparing predictions with an actual derailment at Crescent City, Illinois in June 1970. In this derailment of a 90-car train at 45 mph, 16 cars derailed with 14 piled in close proximity (within less than 200 feet). This jackknifing behavior and stacking of cars together is illustrated in Figure 3. The salient results of this study were:

1. Increasing the number of cars in the train increased the number of derailed cars.
2. Increasing train speed increased the number of derailed cars.
3. Increased braking, weight of cars, and ground friction decreased the number of derailed cars.

Battelle's analysis of the 1982-1985 RAIRS data tends to confirm the first two conclusions. For example, the data were sorted by



Source: Yang, et al, ASME Paper No. 72-WA/RT-2

FIGURE 3. DERAILMENT CONFIGURATIONS FROM DYNAMIC ANALYSIS OF TRAIN DERAILMENTS

train length with the following results in Table 5:

TABLE 5. CARS DERAILED AS A FUNCTION OF TRAIN LENGTH

Length (Cars)	Number of Derailments	Average Length of Train	Average Cars Derailed per train
< 11	111	7	2.9
11-50	1188	32	5.8
51-100	2468	76	8.3
> 100	1795	124	9.5

In TSC's study, results showed that the number of cars derailed versus train length rose from an average of two cars in a five-car train to six cars in a 65-car train, and between six and ten cars for trains longer than 65 cars. For trains more than 30 cars in length, the average train length was 82.4 cars and the average number of cars derailed per train was 6.53 cars. Battelle's limited four-year data base showed an average train length of 81 cars with 8.1 cars per train derailed.

Similarly, the RAIRS data were analyzed for the years 1982-1985 in speed bands of 10 mph. These results are shown in Table 6. Note that 70 trains were standing still, possibly struck (or else the speed column in the data was blank). The average number of cars derailed increased from 5.3 in the lowest speed band to 13.6 in the 51-60 mph band. The average number seems to hit a plateau of 13 cars at speeds above 40 mph, although one accident was noted in the NTSB reports in which 81 cars (the whole train) were derailed.

Derailment details of ten major railroad accidents involving hazardous materials that occurred during this past decade are listed in Table 7. From derailment diagrams in the NTSB reports, we have quantified the groups of cars in close proximity due to jackknifing and piling. These groups of cars would be the most susceptible to intermixing of hazardous materials. Note that in several of the derailments individual groups of derailed cars have resulted, separated by several car lengths of derailed (but not jackknifed) or non-derailed

TABLE 6. TRAIN DERAILMENT ANALYSIS BY TRAIN SPEED: RAIRS DATA FOR CALENDAR YEARS 1982 THROUGH 1985

DERAILMENT ANALYSIS BY TRAIN SPEED --

SPEED (MPH) FROM	TO	NUMBER TRAINS	TOTAL UNITS	AVERAGE LENGTH	DERAILED UNITS	DERAILED UNITS/TRAIN
0	0	70	6388	91	310	4.4
1	10	1766	127951	72	9290	5.3
11	20	1111	89850	80	7022	6.3
21	30	1194	98990	82	10474	8.8
31	40	736	69400	94	8657	11.8
41	50	450	40471	89	5880	13.1
51	60	203	16229	79	2763	13.6
61	70	32	1941	60	427	13.3

TABLE 7. STATISTICS ON RECENT MAJOR RAILROAD ACCIDENTS INVOLVING HAZARDOUS MATERIALS CARS

Report Number (NTSB/-)	Probable Cause	Train Speed (mph)	Train Tonnage	Number Cars in Consist	1st Car Derailed	No. Cars Derailed	Derailed Cars, Close Proximity
HZM-87/01	Track Buckle	45	3,737	44	24	15	7
RAR-86/04	Track Buckle	49	10,548	94	26	42	20, 12
RAR-85/12	Debris on Track	53	6,898	149	2	27	9, 10, 7
RAR-85/05	Axle Bearing Burnoff	35	Unk	88	35	18	Unk
RAR-85/01	Broken Truck Bolster	47	9,043	106	56	38	5, 4, 15
RAR-83/07	Broken Rail	28	6,276	79	33	13	10
RAR-83/05	Bad Track, Faulty Air Hose, Mishandled Brakes	40	11,022	101	16	43	4, 32
RAR-83/04	Train Slack Run-in	64	10,698	129	89	30	7, 3, 9
RAR-83-1	Broken Rail	57	3,883	56	36	14	3, 4
RAR-80-1	Train Slack Run-in, Rail Rollover	30	Unk	53	Loco.	2L, 33	5, 16, 10

TABLE 7. (Continued)

Report Number (NTSB/-)	Cars in Consist	No. Cars Derailed	Location of Derailed Cars by: Thirds 1st	Thirds 2nd	Thirds 3rd	Quarters 1st	Quarters 2nd	Quarters 3rd	Quarters 4th	Haz Mat Cars Derailed	Haz Mat Release	Fire or Explosion	Civilians Evacuated	Est. Cost ($Million)
HZM-87/01	44	15	0	6	9	0	0	10	5	3	Yes	F	> 30,000	3.54
RAR-86/04	94	42	6	36	0	0	22	20	0	14	Yes	F,E	> 2,600	4.34
RAR-85/12	149	27	27	0	0	18	9	0	0	8	Yes	F	Yes (#Unk)	1.29
RAR-86/05	88	18	0	18	0	0	10	8	0	4	Yes	F	2,100	1.38
RAR-86/01	106	38	0	16	22	0	0	25	13	1	Yes	No	> 100	0.58
RAR-83/07	79	13	0	13	0	0	9	4	0	2	Yes	No	No	0.20
RAR-83/05	101	43	18	25	0	10	25	8	0	29	Yes	F,E	3,000	14 +
RAR-83/04	129	30	0	0	30	0	0	8	22	1	Yes	F	No	1.23
RAR-83-1	56	14	0	2	12	0	0	7	7	1	No	No	No	1.02
RAR-80-1	53	2L, 33	17	16	0	13	13	7	0	24	Yes	F,E	Unk.	Unk.
Totals	899	273	68	132	73	41	88	97	47					
Percent	---	100	25	48	27	15	32	36	17					

cars. An extreme example of jackknifing/piling is shown in Figure 4, the Livingston, Louisiana derailment (NTSB/RAR-83-05). In this derailment, a major pile of 32 cars had occurred. Note in Table 7 that the locations of derailed cars by train segments (thirds or fourths) confirms, for major accidents, the results cited in the previous section for accident statistics in general.

2.3 Review of Past Accidents

A review of past railroad accidents (not just derailments) was conducted to identify those involving cars carrying hazardous materials. Of interest were those accidents which involved the release of hazardous materials; especially those where mixing of the released materials occurred. This activity utilized the FRA's Accident/Incident Bulletins, and various NTSB railroad accident reports, summary reports, and special study reports issued during the period 1968 through 1987 as its primary information sources. Additional selected items were utilized as appropriate.

A summary overview of current statistics for train accidents involving hazardous materials is provided in Table 8. Additional, related information was previously provided in Tables 3 and 4 and the discussion associated with them. The source of data for these three tables (Section 4 - Accidents Involving Consists Transporting Hazardous Materials-within the FRA Accident/ Incident Bulletins) contained the following cautionary notice:

> "The information in this section represents only those accidents involving consists that contained at least one car carrying hazardous materials. The number of accidents, resulting damages, or casualties may or may not be attributable to the presence of these cars in the consists. While this does not represent a complete accounting of all hazardous materials releases, it does provide some insight into the extent of hazardous materials car involvement in train accidents."

From the contents of Tables 4 and 8, it can be concluded that for the three-year period calendar years 1983, 1984, and 1985, there was

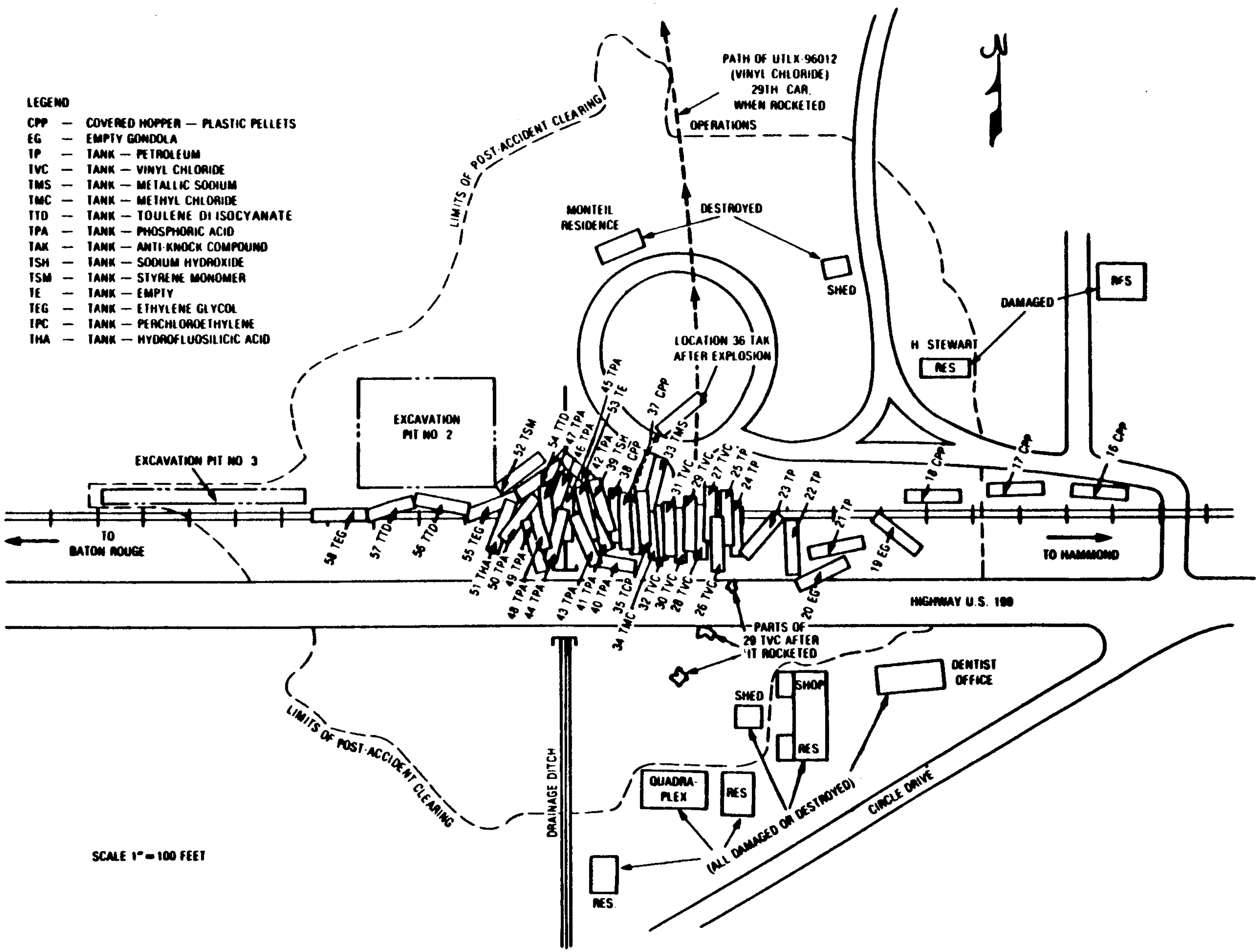


FIGURE 4. PLAN VIEW OF MAJOR DERAILMENT (NTSB/RAR-83/05)

TABLE 8. TRAIN ACCIDENTS INVOLVING CONSISTS TRANSPORTING HAZARDOUS MATERIALS FOR CALENDAR YEARS 1979-1986.

Year	Total Number Of Accidents	Accidents In Which A Hazmat Car Was Damaged Or Derailed	Accidents In Which There Was A Release of Hazardous Materials	Accidents Which Resulted In A Evacuation
1979	819	456	119	34
1980	926	480	105	44
1981	586	353	77	27
1982	494	286	59	13
1983	422	240	52	16
1984	436	237	54	17
1985	415	245	54	22
1986	364	185	51	32

NOTE: An accident may appear in more than one column. For example, an accident that resulted in a release would also be included in the count of accidents that resulted in a hazardous materials car being damaged or destroyed.

(Source: FRA Accident/Incident Bulletin Nos. 153 and 155).

an average of 435 accidents per year in which the trains involved contained hazmat cars. This was 11.6 percent of the total number of accidents. Also, there was an average of 53 accidents per year in which a release of hazardous materials occurred. Further, there was an average of 590 cars containing hazmat damaged each year, and an average of 90 cars per year released hazardous materials.[13] This data can be interpreted to imply that the typical/average accident of trains carrying hazmat resulted in 1.36 hazmat cars being damaged. In those accidents where releases occurred (12.2 percent of the total), 1.70 cars released. From these numbers, it would appear that instances where the mixing of released hazardous materials occurred would be rare. It is, however, recognized that accidents do occur which involve damage to numerous hazmat cars and the release of several hazardous materials.

Neither the RAIRS tapes nor the Accident/Incident Bulletins provide any information relative to the nature of the hazardous materials involved or released during accidents. Therefore, the investigation into instances where such materials released and mixed, and the consequences thereof, was initiated by identifying NTSB reports which might be applicable. In addition to an initial listing provided by FRA's project monitor, the Battelle Transportation Library was searched as was the TRIS data base. The result was a collection of NTSB-authored materials in complete and/or abstract form. Table 9 lists those items related to accidents involving hazmat releases.[14]

A review of the various hazmat accidents described in Railroad Accident Reports (RARs) listed in Table 9 did not uncover any specific instances where it was reported that the actual mixing of released incompatible hazardous materials resulted in worsened accident situations or related conditions. It was noted that in the Miamisburg, Ohio derailment (Item 1 in Table 9), where both yellow phosphorus and molten

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13 Note that the more restricted data base (mainline track, freight or mixed trains) showed 1983-1985 averages of 289 hazmat cars/year damaged, 58 cars/year releasing.

14 A considerably larger number of items relating to railroad accidents of various types were identified. However, only those involving hazmat releases are listed here.

TABLE 9. NTSB REPORTS RELATING TO RAILROAD ACCIDENTS INVOLVING HAZMAT RELEASES (THROUGH 1987)

1. NTSB-HZM-87-01. Hazardous Materials Release Following the Derailment of Baltimore and Ohio Railroad Company Train No. SLFR, Miamisburg, Ohio, July 8, 1986.

2. NTSB-RAR-86-04. Derailment of St. Louis Southwestern Railway Company (Cotton Belt) Freight Train Extra 4835 North and Release of Hazardous Materials near Pine Bluff, Arkansas, June 9, 1985.

3. NTSB-RAR-85-12. Derailment of Seaboard System Railroad Train No. F-690 With Hazardous Material Release, Jackson, South Carolina, February 23, 1985 and Collision of Seaboard System Railroad Train No. F-481 With Standing Cars, Robbins, South Carolina, February 25, 1985.

4. NTSB-RAR-85-10. Denver and Rio Grande Western Railroad Company Train Yard Accident Involving Punctured Tank Car, Nitric Acid and Vapor Cloud, and Evacuation, Denver, Colorado, April 3, 1983.

5. NTSB-RAR-85-08. Vinyl Chloride Monomer Release From a Railroad Tank Car and Fire, Formosa Plastics Corporation Plant, Baton Rouge, Louisiana, July 30, 1983.

6. NTSB-RAR-85-05. Seaboard System Railroad Freight Train FERHL Derailment and Fire, Marshville, North Carolina, April 10, 1984.

7. NTSB-HZM-85-03. Anhydrous Hydrogen Fluoride Release, Elkhart, Indiana, February 4, 1985.

8. NTSB-RAR-85-02. Rear End Collision Between Conrail Trains OIPI-6 and ENPI-6X Near Saltsburg, Pennsylvania, February 26, 1984.

9. NTSB-SIR-85-02. Railroad Yard Safety--Hazardous Materials and Emergency Preparedness, (April 30, 1985).

10. NTSB-SIR-85-01. Release of Oleum During Wreckage-Clearing Following Derailment of Seaboard System Railroad Train Extra 8294 North, Clay, Kentucky, February 5, 1984.

11. NTSB-RAR-83-07. Illinois Central Gulf Railroad Company Freight Train Derailment, Fort Knox, Kentucky, March 22, 1983.

12. NTSB-RAR-83-05. Derailment of Illinois Central Gulf Railroad Freight Train Extra 9629 East (GS-2-28) and Release of Hazardous Materials at Livingston, Louisiana, September 28, 1982.

TABLE 9. (Continued)

13. NTSB-RAR-83-04. Derailment of Seaboard Coast Line Railroad Train No. 120 at Colonial Heights, Virginia, May 31, 1982.

14. NTSB-RAR-83-01. Derailment of Southern Pacific Transportation Company Train No. 01-BSMFF-05 Carrying Radioactive Material at Thermal, California, January 7, 1982.

15. NTSB-RAR-81-08. Derailment of SP at Surf, CA, May 22, 1981.

16. NTSB-RAR-81-01. Illinois Central Gulf Railroad Company Freight Train Derailment, Hazardous Material Release and Evacuation, Muldraugh, Kentucky, July 26, 1980.

17. NTSB-HZM-81-01. Phosphorus Trichloride Release in Boston and Maine Yard 8 During Switching Operations, Somerville, Massachusetts, April 3, 1980.

18. NTSB-HZM-80-01. The Accident Performance of Tank Car Safeguards, (March 8, 1980).

19. NTSB-RAR-79-11. Louisville and Nashville Railroad Company Freight Train Derailment and Puncture of Hazardous Materials Tank Cars, Crestview, Florida, April 8, 1979.

20. NTSB-HZM-79-04. Survival in Hazardous Materials Transportation Accidents.

21. NTSB-HZM-79-03. Special Investiagtion Report. Onscene Coordination Among Agencies at Hazardous Materials Accidents. September 1979.

22. NTSB-SR-79-03. Safety Report on the Progress of Safety Modifications of Railroad Tank Cars Carrying Hazardous Materials. September 1979.

23. NTSB-HZM-79-02. Noncompliance with Hazardous Materials Safety Regulations. August 1979.

24. NTSB-RAR-79-02. Head-End Collision of Louisville and Nashville Railroad Local Freight Train and Yard Train at Florence, Alabama, September 18, 1978.

25. NTSB-SEE-79-02. Safety Effectiveness Evaluation of the Federal Railroad Administration's Hazardous Materials and Track Safety Programs, (March 8, 1979).

26. NTSB-RAR-79-01. Derailment of Louisville and Nashville Railroad Company's Train No. 584 and Subsequent Rupture of Tank Car Containing Liquified Petroleum Gas, Waverly, Tennessee, February 22, 1978.

TABLE 9. (Continued)

27. NTSB-RAR-78-08. St. Louis Southwestern Railway Company Freight Train Derailment and Rupture of Vinyl Chlordie Tank Car, Lewsiville, Arkansas, March 29, 1978.

28. NTSB-RAR-78-07. Derailment of Atlanta and Saint Andrews Bay Railway Company Freight Train, Youngstown, Florida, February 26, 1978.

29. NTSB-RAR-78-04. Louisville and Nashville Railroad Company Freight Train and Puncture of Anhydrous Ammonia Tank Cars at Pensacola, Florida, November 9, 1977.

30. NTSB-SEE-78-02. Analysis of Proceedings of the NTSB into Derailments and Hazardous Materials, April 4-6, 1978.

31. NTSB-RHR-78-1. Collision of a Louisiana and Arkansas Railway Freight Train and a L.V. Rhymes Tractor-Semitrailer at Goldonna, Louisiana, December 28, 1977.

32. NTSB-RAR-77-07. Derailment of a Burlington Northern Freight Train at Belt, Montana, November 26, 1976.

33. NTSB-RAR-77-02. Chicago and North Western Transportation Company Freight Train Derailments and Collision, Glen Ellyn, Illinois, May 16, 1976

34. NTSB-RAR-77-01. St. Louis Southwestern Railway Company Vinyl Chloride Tank Car, Lewisville, Arkansas, March 24, 1978.

35. NTSB-RAR-76-08. Derailment of Tank Cars With Subsequent Fire and Explosion on Chicago, Rock Island and Pacific Railroad Company Near Des Moines, Iowa, September 1, 1975.

36. NTSB-RAR-76-01. Burlington Northern Inc., Monomethylamine Nitrate Explosion, Benson, Arizona, May 24, 1973.

37. NTSB-RAR-75-07. Hazardous Materials Accident at the Southern Pacific Transportation Company's Englewood Yard in Houston, Texas, September 21, 1974.

38. NTSB-RAR-75-06. Collision of St. Louis-San Francisco Railway Trains 3210 and 3211, Mustang, Oklahoma, September 1, 1974.

39. NTSB-RAR-75-04. Hazardous Materials Accident in the Railroad Yard of the Norfolk and Western Railway at Decatur, Illinois, July 19, 1974.

40. NTSB-RAR-75-02. Southern Pacific Transportation Company Freight Train 2nd BSM Munitions Explosion, Benson, Arizona, May 24, 1973.

TABLE 9. (CONTINUED)

41. NTSB-RAR-74-04. Derailment and Subsequent Burning of Delaware and Hudson Railway Freight Train at Oneonta, New York, February 12, 1974.

42. NTSB-RAR-73-01. Hazardous Materials Railroad Accident in the Alton and Southern Gateway yard in East St. Louis, Illinois, January 22, 1972.

43. NTSB-RAR-72-06. Derailment of Missouri Pacific Railroad Company's Train 94 at Houston, Texas, October 19, 1971.

44. NTSB-RAR-72-02. Derailment of Toledo, Peoria and Western Railroad Company's Train No. 20 with Resultant Fire and Tank Car Ruptures, Crescent City, Illinois, June 21, 1970.

45. NTSB-RAR-72-01. Penn Central Transportation Company Freight Train Derailment Passenger Train Collision with Hazardous Material Car, Sound View, Connecticut, October 8, 1970.

46. NTSB-RAR-71-02. Chicago, Burlington and Quincy Railroad Company Train 64 and Train 824 Derailment and Collision with Tank Car Explosion, Crete, Nebraska, February 18, 1969.

47. NTSB-STS-71-1. Risk Concepts in Dangerous Goods Transportation Regulations.

48. NTSB-RAR-70-02. Illinois Central Railroad Company Train Second 76 Derailment at Glendora, Mississippi, September 11, 1969.

49. NTSB-RAR-69-01. Southern Railway Company Train 154 Derailment with Fire and Explosion, Laurel, Mississippi, January 25, 1969.

50. NTSB-RAR-68-03. Pennsylvania Railroad Train PR-11A, Extra 2210 West and Train SW-6, Extra 2217 East Derailment and Collision, Dunreith, Indiana, January 1, 1968.

sulfur were released, there was considerable concern over the possibility of mixing. Guide No. 49 of the NFPA guide indicated that when a mixture of sulfur and yellow phosphorous is warmed, the two elements unite with vivid combustion and a powerful explosion. However, mixing did not occur.

Many hazmat accidents involve only a single hazardous material which may release from one or more individual cars. Initial or subsequent fires (with harmful combustion effluents) and explosions are common consequences of hazmat accidents. Certain materials (e.g. vinyl chloride, liquid petroleum gas) commonly ignite upon release. Additional consequences are the formation of toxic (e.g. anhydrous ammonia) or combustible vapor clouds; in many instances the latter ignite and/or explode. In many past accidents, the heat or flame from the initial fire(s) impinged upon other cars which, depending upon their contents, later exploded and rocketed. In this regard, the potential for fire induced rupture of a car containing a second material, or even more of the initial material, may inhibit fire-fighting and rescue activities and necessitate extensive evacuation of the area. Evacuation is commonly prompted by existing or potential toxic vapor clouds and potential explosions. Also, heat and smoke associated with the initial accident can prevent railroad and/or emergency forces from accurately surveying the accident to determine the condition of the hazmat cars. Further, danger of explosion can inhibit all accident related activities even when suitable equipment is available to combat the initial accident effects.

There are well-publicized examples of hazmat accidents which involved multiple hazardous materials. Among these are the Miamisburg, Ohio (Table 9, Item 1), Pine Bluff, Arkansas (Item 2), Livingston, Louisiana (Item 12) and Paxton, Texas (Item 18) accidents. The contents and disposition of the derailed cars involved in these accidents are noted in Table 10. However, while the potential for the mixing of incompatible combinations of hazardous materials appeared to exist, no direct mention of this was made in the NTSB accident reports.

In order to assess the actual and/or potential effects of hazardous materials mixing in these four accidents, a special review was conducted. All possible binary combinations of materials were evaluated,

TABLE 10. EXAMPLES OF 34 POTENTIAL HAZARDOUS MATERIALS MIXING DURING TRAIN DERAILMENT ACCIDENTS

1. NTSB/HZM-87-01
   Miamisburg, Ohio, 7-8-86, Baltimore & Ohio Railroad

   Car 30 - yellow phosphorous (spilled, burned)
   Car 33 - molten sulfur (spilled, mixed)
   Car 34 - tallow (spilled, mixed)

2. NTSB/RAR-86/04
   Pine Bluff, Arkansas, 6-9-85, SLSW (Cotton Belt) Railway

   Car 26 - vinyl chloride (insulated, intact, saved by firefighters)
   Car 27 - vinyl chloride (insulated, intact, saved by firefighters)
   Car 28 - polyethylene polyphylisocyanate (exploded in resulting fire)
   Car 29 - polyethylene polyphylisocyanate (burned in fire)
   Car 30 - polyethylene/polypropylene pellets (burned)
   Car 31 - polyethylene/polypropylene pellets (burned)
   Car 32 - butyl acrylate (spilled, burned)
   Car 33 - butyl acrylate (spilled, burned)
   Car 34 - acrylic acid (disposition unknown)
   Car 35 - polyethylene/polypropylene pellets (burned)
   Car 36 - ethylene oxide (exploded in fire)
   Car 37 - polyethylene/polypropylene pellets (burned)

3. NTSB/RAR-83/05
   Livingston, Louisiana, 9-28-82, ICG Railroad

   Cars 24-55 piled in close proximity, contents of 30 tank cars totally or partially destroyed as follows.:

Vinyl chloride	163,043 gal	1,241,000 lb
Styrene monomer	23,145	176,000
Anti-knock compound	5,666	75,000
Toluene diisocyanate	2,259	23,000
Phosphoric acid	148,552	2,100,000
Hydrofluosilicic acid	19,780	200,000
Sodium hydroxide	15,363	195,000
Perchloroethylene	14,028	190,000
Ethylene glycol	20,840	194,000

TABLE 10. (Continued)

4. NTSB/HZM-80-1
Paxton, Texas, 6-8-79, Southern Pacific Railroad

Car 6 - isobutylene (fire breached, burned)
Car 7 - butadiene (released, burned)
Car 8 - tetrahydrofuran (violent rupture in fire)
Car 9 - hydrogen fluoride (survived)
Car 10 - propylene glycol (leaked
Car 11 - propylene glycol (leaked)
Car 12 - propylene glycol (leaked)
Car 13 - dibasic ester (survived)
Car 14 - ethylene oxide (violent rupture in fire)
Car 15 - vinyl acetate (spilled, burned)
Car 16 - ethylene glycol (spilled)
Car 17 - methanol (leaked, burned)
Car 18 - ethyl acrylate (spilled, burned)
Car 19 - acetaldehyde (spilled, burned)
Car 20 - acetaldehyde (spilled, burned)
Car 21 - acetaldehyde (spilled, burned)
Car 22 - plastic pellets (disposition not known)
Car 23 - plastic pellets (disposition not known)
Car 24 - plastic pellets (disposition not known)
Car 25 - rubber (disposition not known)
Car 26 - acetaldehyde (spilled, burned)
Car 27 - empty tank car (survived)
Car 28 - empty tank car (survived)
Car 29 - empty tank car (survived)
Car 30 - butadiene (exposed to fire, survived)
Car 31 - butadiene (survived)
Car 32 - vinyl acetate (survived)
Car 33 - butadiene (survived)

even though in some cases the tank cars remained intact and, as such, could not have contributed to the consequences. The purpose of this approach was to determine if the situation could have become even worse if the tank car had leaked or ruptured. The thermal effects of fire on the stability of the chemicals in the tank cars were considered. Results of this review are as follows:

<u>**NTSB/HAZ-87/01 (Table 9, Item 1)**</u>: Based on observation, tallow was mixed with molten sulfur, but the mixture did not burn. The tallow may have minimized or prevented the molten sulfur from burning. Therefore, mixing of chemicals during this train derailment did not make matters worse as compared with the consequences of spilling chemicals without mixing, but rather, may have somewhat mitigated the consequences.

<u>**NTSB/RAR-86-04 (Table 9, Item 2)**</u>: Polymerization reactions resulting in the formation of heat may have occurred during the derailment. It is possible that the heat generated from these reactions initiated a fire as well as caused formation of flammable vapors which intensified the fire. Mixing of chemicals during this train derailment therefore may have worsened the consequences as compared with spilling the chemicals without mixing. Because of the potential for thermal instability of chemicals such as ethylene oxide and polymerizable chemicals when heated in confined containers such as tank cars, segregation of these chemicals from other flammable chemicals in a train should be considered.

<u>**NTSB/RAR-83-05 (Table 9, Item 12)**</u>: Reactions, some of which are violent, may have occurred during the derailment. The resultant formation of considerable heat and flammable products (i.e. ethane gas) could have contributed to the initiation and intensity of the fire. Mixing of chemicals during this train derailment may have worsened the results as compared with the consequences of spilling the chemicals without mixing. Because of the potential for thermal instability of chemicals such as tetraethyl lead and polymerizable

chemicals such as vinyl chloride when heated in confined containers such as tank cars, segregation of these chemicals from other flammable chemicals in a train should be considered.

NTSB/HZM-80/01 (Table 9, Item 18): Reactions, some of which are violent, may have occurred during this accident resulting in the formation of heat and flammable gaseous products. These reactions could have contributed to the initiation and intensity of the fire. Of primary concern are the reactions of acetaldehyde with acids (e.g. hydrogen fluoride), glycols (e.g. propylene glycol and ethylene glycol), and alcohols (e.g. methanol); and the reactions of acids such as hydrogen fluoride with ethylene oxide, vinyl acetate, glycols and methanol. These combinations should be avoided by segregation of tank cars in the train. Also, because of the potential for thermal instability of chemicals that can form organic peroxides (e.g. tetrahydrofuran), segregation of these chemicals from other flammable chemicals in a train should be considered.

The complete results of the review of these four accidents is contained in Appendix C of this report.

As suggested by the previously-cited statistics related to hazmat accidents, car damage and releases, there has not in general been a substantial problem associated with the mixing of incompatible hazmat releases. However, the actual or potential consequences cited in three of the four accidents reviewed above show that the problem is real and potentially catastrophic.

2.4 Review of Current Regulations

In this activity the current U.S. DOT regulations, and those of the Canadian Transport Commission, pertaining to the placement of hazmat cars within trains were reviewed and compared. The DOT regulations were specified by the FRA to be in 49 CFR Subpart C (174.81) and Subpart D (174.83 through 174.93) (full copies are provided in Appendices D and E). The cited Canadian regulations (Subpart E, §74.575 - §74.589) are related to "handling cars", only a portion of which is directly concerned with the position of cars in trains.[15] The applicable items contained therein are:

1. Item (c)(3). "When transporting a car placarded with a placard with a square background in a terminal, or yard, or on a side track or siding, the car shall be separated from the engine by at least one non-placarded car."

2. Item (f). "A car carrying dangerous goods shall not be marshalled next to a car described in a column other than column 3 or 4 of the table shown on page 173 if an X appears in that column on the line corresponding to type of car carrying the dangerous goods (as described in column 1) and the placard groups of the dangerous goods (as indicated in column 2)." The cited table is entitled "Position in Freight or Mixed Train of Cars Containing Dangerous Commodities", and is contained in Appendix E of this report.

Only the second of these two items is of interest to this study.

Item (f) of the Canadian regulations imposes placement restrictions upon hazmat cars which are related to both the "type of car" and the "placard group number" of its contents. The groups, as defined therein, consist of one or more classes and/or divisions of hazardous materials. Canada has implemented a national system of regulations based on United Nations Recommendations. Descriptions of these groups are as follows:[16]

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15 §74.589-Handling Cars consists of 6 major parts; (a) Definitions, (b) Placards on Cars, (c) Switching of Cars Containing Dangerous Commodities, (d) Placement of Freight Cars Placarded with Placard with a Square Background in Yards, on Sidings, or Side Track, (e) Notice to Train Crews on Placarded Cars, and (f) Position of Cars in Trains. Most of these have multiple subparts.

16 The primary parts of these descriptions are taken directly from the regulations. The portions in parentheses have been added to facilitate the use of this material; it is not claimed that these are fully complete or accurate. Definitions of the generic hazmat (e.g., "oxidizer") are provided in Appendix F.

- Group 1 consists of Divisions 1.1 and 1.2 (i.e. explosives-mass and explosives-projectile).

- Group 2 consists of explosives-fire hazard (1.3); explosives-no significant blast hazard (1.4); explosives-insensitive (1.5); flammable gases (2.1), non-flammable gases, compressed, nontoxic (2.2); poisonous gases (2.3); flammable liquids (3.1-3.3); flammable solids, FS (4.1); pyrophoric liquids or solids (4.2); dangerous when wet flammable soilds (4.3); oxidizing materials (5.1); organic peroxide materials (5.2); poisonous substances (6.1); infectious substances (6.2), and corrosive materials (8).

- Group 3 consists of Cyanogen Chloride, Hydrogen Cyanide, Nitric Oxide, Phosgene, Nitrogen Dioxide, Phosphine, Diborane or Diborane Mixtures, Arsine, Boron Trifluoride, Carbonyl Sulfide, Cyanogen, Nitric Oxide and Nitrogen Tetroxide Mixtures, Nitrogen Oxides n.o.s. and Nitrogen Trioxide (i.e. primarily Poison A substances; some corrosive or oxidizing; some flammable gases).

- Group 4 consists of Class 7 (i.e. radioactive)

- Group 5 consists of tank cars carrying Division 3.3 materials or tank cars placarded "RESIDUE" or "EMPTY" (i.e. pyroforic liquid and cars with the potential for volatile fumes).

- Group 6 consists of Class 9, and of Class 6 bearing St. Andrews cross placards (i.e. "other regulated materials-ORM", and poisonous materials which must be kept away from food).

The cited U.S. regulations are related to two specific topics. §174.81 is concerned with the "segregation and separation requirements for hazardous materials in rail cars" while Subpart D is concerned with "handling of placarded cars". Only the latter is of direct interest here since it contains language pertaining to the position of cars in trains, while the former does not. Further, only a portion of Subpart D[17] is directly concerned with the position of cars in trains. The applicable sections contained therein are:

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17 Subpart D-Handling of Placarded Cars consists of eleven major sections §174.83 through 174.93 inclusive (see Appendix D).

1. §174.83 Switching of cars containing hazardous materials, Item (c). "When transporting a car placarded EXPLOSIVES A in a terminal, yard, or on a side track, or siding, it must be separated from the engine by at least one non-placarded car.

2. §174.86 Position in train of cars placarded "EXPLOSIVES A" or POISON GAS" when accompanied by cars carrying guards or technical monitors (see details in Appendix D).

3. §174.87 Placarded cars prohibited in passenger trains, limited in mixed trains (see Appendix D).

4. §174.88 Position in train of car placarded "EXPLOSIVES A" (see Appendix D).

5. §174.89 Position in train of cars placarded "RADIOACTIVE" (see Appendix D).

6. §174.90 Separating cars placarded "EXPLOSIVES A" or "POISON GAS" from other cars in trains (see Appendix D).

7. §174.91 Position in train of loaded placarded tank car other than car placarded "COMBUSTIBLES" (see Appendix D).

8. §174.92 Separating loaded placarded tank cars other than cars placarded "COMBUSTIBLE" from other cars in trains (see Appendix D).

9. §174.93 Position in train of a tank car displaying RESIDUE placards (see Appendix D)

Only Items 2 through 9 of the above are of interest to this study.

Unlike the Canadian regulations, which utilize a table to convey their placement restrictions, those of the U.S. are entirely descriptive in nature. However, to assist its membership in utilizing these regulations, the Association of American Railroads, via its Bureau of Explosives, has published related materials.[18] It can be expected that the U.S. railroad industry uses the AAR materials as a major source

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18 The AAR materials include Poster No. 1 (Excerpts from DOT Regulations for Transportation of Explosives and Other Dangerous Articles of Freight ...) which essentially repeats all text of Subpart D, and Poster No. 4 (Position in Train of Placarded Cars Containing Hazardous Materials) which displays the contents of Post No. 1 in tabular/matrix format. A representation of the latter is provided here in Appendix G. However, it does not contain the "instructions for use" included on the AAR poster.

of guidance in the placement of hazardous materials cars within trains. These may have become the de facto regulations for hazmat car placement in the U.S.

The U.S. regulations concerned with the placement of hazmat cars within trains are primarily stated in terms of placement restrictions for specific placard destinations,[19] although type of car is also a factor. They are couched in terms of "minimum separation" or "prohibited locations" for placarded cars relative to other units in a train. Depending upon the specific placard designation under consideration, they relate to one or more of the following:

1. People on board, including train crews, cargo guards/attendants, and (in mixed trains) passengers.
2. Selected other placarded cars (e.g. cars placarded EXPLOSIVES A can not be placed next to cars placarded POISON GAS).
3. Other cars containing sources of ignition (e.g. heat, flame, combustion engines).
4. Other cars with protruding lading or the possibility for such due to load shifting.
5. Other cars with lading which could be damaged from close proximity alone.

There are some differences in restrictions related to type of car (i.e. tank car or not) for identical placards. In general, for the same placard, restrictions are more severe for "tank cars" than for "other than tank cars". For example, tank cars placarded POISON GAS must not be positioned nearer than 6th from engine, occupied caboose or passenger car, while "other than tank cars" are not so restricted. Similarly, there are numerous placement restrictions on tank cars with "any placarded load other than COMBUSTIBLE or POISON GAS" which do not apply to "other than tank car". We can speculate that the reason for this is because tank cars carry liquid or gaseous hazmat cargoes, while other types of cars would contain solid or dry hazmat cargoes.

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19 The cited designations are "EXPLOSIVES A", "POISON GAS", "COMBUSTIBLES", "RADIOACTIVE", "RESIDUE", and "other".

Some of the restrictions pertaining to separation from train crews are partially relaxed when the train length is not sufficient to permit their full implementation. It appears that, with the possible exception of situations involving Item 4 above, any number of cars bearing the same placard can be placed in adjacent train positions. In consequence, "incompatible" hazardous materials need, at the most, be placed only one car length apart.

A direct item-by-item comparison of the U.S. and Canadian regulations is somewhat hampered by the differences in the content of the placard designations used by the former, and the placard group numbers used by the latter. However, both relate their specific restrictions according to type of car, type of hazardous material, location of people on train, length of train, presence of ignition sources, presence of cars with protruding lading (actual or potential), and other hazardous materials cars. As with the U.S. regulations, except for most occupied units, the Canadian regulations primarily prohibit adjacent placement of specified placard groups. The Canadian regulations waive some of their restrictions on proximity to occupied cars when the train consists of placarded tank cars only. But, they impose additional separation requirements on tank cars containing flammable gases.[20]

On the whole, the U.S. and Canadian regulations are similar and compatible, although in some instances an interchange of consists would require revising the positions of selected hazmat cars. For example, Canadian railroads may have to reposition a car received from the U.S. containing flammable gas in order to conform to the above cited requirements. Likewise, U.S. railroads may have to reposition hazmat cars which have associated guard cars. While not examined as a part of this study, both sets of railroads may need to interpret the placards on cars received and/or replacard them so as to conform to practices and regulations pertaining to the receiving railroad. This could result in the need for additional repositioning requirements.

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20 Tank cars containing flammable gases (Division 2.1 of Class 2 per IMCO classification) must be separated from tank car shipments of Chlorine, Anhydrous Ammonia, and Sulphur Dioxide by 5 cars.

3.0 TASK ITEM 2 -- HAZARDOUS MATERIALS COMPATIBILITY

Task Item 2 was the second of the six items which comprise Task Order No. 6. It consisted of two interrelated activities as follows:

2-1. Analyze the top 100 hazardous commodities given in the 1986 Top 125 Hazardous Commodities Movements by Tank Car Volume list to determine the extent to which they are incompatible. Group them into their natural chemical categories and use the basic category incompatabilities to indicate where the greatest hazards exist. From this determine specific commodity incompatabilities.

2-2. Utilize the results of the above analysis and the basic characteristics of the commodities (e.g. dry, liquid, vaporization rate) to determine minimum segregation distances in a train to avoid commingling in a derailment scenario.

In this task item, hazardous commodities were analyzed to determine if additional restrictions should be required for placement of cars in a train consist based on potential mixing of commodities during a derailment. The analyses focused on the top 100 hazardous commodities given in the "1986 Top 125 Hazardous Commodities Movements by Tank Car Volume List" (See Table 11) along with "Sodium Metal" (ranked 101) and "Fuming Nitric Acid" (441 tank car movements per year). Sodium metal was included because of the undesirable consequences resulting from mixing with many of the top 100 commodities. Fuming nitric acid was included based on a request from the FRA.

The approach of the study is described as follows. The compatibilities of the hazardous commodities were first determined in binary combinations. Consequences were then identified for each incompatible combination. Types of consequences that were considered included:

- Toxic chemical releases
- Fireballs
- Unconfined Vapor Cloud Explosions
- Condensed Phase Explosions

TABLE 11. 1986 TOP 125 HAZARDOUS COMMODITIES MOVEMENTS BY TANK CAR

Rank	STC Code	Commodity	Haz. Class	Total Tank Movements	Total Commodity Moves
1.	4935243	Sodium Hydroxide, Liq. or Solution	CM	48,367	48,384
2.	4904120	Chlorine	NG	46,686	46,721
3.	4930040	Sulfuric Acid	CM	46,265	46,466
4.	4904210	Anhydrous Ammonia	NG	42,526	42,561
5.	4905752	Liquefied Petroleum Gas	FG	37,043	37,542
6.	4930247	Phosphoric Acid	CM	28,008	28,152
7.	4935240	Sodium Hydroxide, Liq. or Solution	CM	27,274	27,452
8.	4905781	Liquefied Petroluem Gas	FG	21,793	21,857
9.	4905792	Vinyl Chloride	FG	20,081	20,086
10.	4909230	Methyl Alcohol	FL	18,109	18,173
11.	4915112	Fuel Oil	CL	17,767	18,398
12.	4915111	" "	CL	14,038	14,122
13.	4905706	Butane	FG	12,215	12,241
14.	4930228	Hydrochloric Acid	CM	10,973	11,063
15.	4907265	Styrene Monomer, Inhibited	FL	10,859	10,863
16.	2911735	Petroleum, Partially Refined	--	10,658	10,662
17.	4910165	Crude Oil Petroleum	FL	9,995	10,002
18.	4905702	Butane	FG	9,473	9,477
19.	4909151	Denatured Alcohol	FL	8,947	8,961
20.	4904509	Carbon Dioxide, Refrigerated Liquid	NG	8,172	8,207
21.	2911715	Petroleum Residual Fuel Oil	--	7,907	7,943
22.	4908178	Gasoline	FL	7,676	7,709
23.	4905747	Liquefied Petroleum Gas	FG	7,582	7,599
24.	4915113	Fuel Oil	CL	7,443	9,358
25.	4905704	Butadiene, Inhibited	FG	7,025	7,026
26.	2911315	Distillate Fuel Oil	--	6,549	6,641
27.	4906610	Ethylene Oxide	FL	6,535	6,548
28.	4915259	Petroleum naptha	CL	6,061	6,076
29.	4921220	Phenol	PB	5,974	5,979
30.	4905782	Liquefied Petroleum Gas	FG	5,707	5,709
31.	4935645	Hexamethylene Diamine Solution	CM	5,580	5,592
32.	4905750	Liquefied Petroleum Gas	FG	5,360	5,360
33.	4908110	Benzene	FL	5,067	5,068
33.	4906620	Propylene Oxide	FL	4,913	4,914
35.	4909215	Fuel, Aviation, Turbine Engine	FL	4,874	4,880
36.	4906420	Acrylonitrile	FL	4,811	4,814
37.	4930042	Sulfuric Acid, spent	CM	4,809	4,817
38.	4907270	Vinyl Acetate	FL	4,431	4,432
39.	4910259	Petroleum Naptha	FL	4,132	4,167
40.	4916141	Phosphorus, White or Yellow	FS	3,533	3,649
41.	4907210	Acetaldehyde	FL	3,520	3,520
42.	4915257	Petroleum Naptha	CL	3,348	3,355

TABLE 11. (Continued)

Rank	STC Code	Commodity	Haz. Class	Total Tank Movements	Total Commodity Moves
43.	4930030	Oleum	CM	3,243	3,249
44.	4909141	Denatured Alcohol	FL	3,140	3,166
45.	4915185	Combustible Liquid, n.o.s.	CL	3,139	3,422
46.	4908105	Acetone	FL	2,971	3,010
47.	4904290	Sulfur Dioxide	NG	2,959	2,959
48.	4931303	Acetic Acid, Glacial	CM	2,953	2,969
49.	4907250	Methyl Methacrylate Monomer, Inhib.	FL	2,927	2,977
50.	4936540	Corrosive Liquid, n.o.s.	CM	2,916	3,974
51.	4909351	Xylene	FL	2,869	2,873
52.	4909205	Isopropanol	FL	2,848	2,957
53.	4905707	Liquefied Petroleum Gas	FG	2,806	2,835
54.	4909237	Methyl Alcohol	FL	2,630	2,633
55.	4935230	Potassium Hydroxide, Liq. or Solution	CM	2,622	2,675
56.	4921575	Toluene Diisocynate	PB	2,610	2,655
57.	4909350	Xylene	FL	2,546	2,591
58.	4930024	Hydrogen Fluoride	CM	2,464	2,466
59.	4910185	flammable Liquid, n.o.s.	FL	2,256	3,580
60.	4913168	Formaldehyde Solution	CL	2,157	2,157
61.	4908132	Cyclohexane	FL	2,089	2,090
62.	4909305	Toluene	FL	2,084	2,105
63.	4912215	Butyl Acrylate (Corr. L., n.o.s.)	CL	1,957	1,963
64.	4932342	Ferric chloride Solution	CM	1,883	1,888
65.	4918774	Ammonium Nitrate Solution	OM	1,860	1,862
66.	4913158	Octyl Alcohol (C.L., n.o.s.)	CL	1,671	1,671
67.	4918335	Hydrogen Peroxide Solution	OM	1,646	1,655
68.	4931304	Acetic Anhydride	CM	1,533	1,543
69.	4908183	Hexane	FL	1,454	1,475
70.	2911190	Gasoline, nec	--	1,410	1,480
71.	4915245	Oil	CL	1,407	1,425
72.	4940320	Carbon Tetrachloride	OA	1,343	1,343
73.	4909243	Methyl Ethyl Ketone	FL	1,318	1,351
74.	4915167	Fuel, Aviation, Turbine Engine	CL	1,283	1,283
75.	4915147	Compound, Cleaning, Liquid	CL	1,281	1,325
76.	4907215	Ethyl Acrylate, Inhibited	FL	1,281	1,281
77.	4910102	Alcoholic Beverage	CL	1,276	1,379
78.	4915363	Coal Tar Distillate	CL	1,259	1,264
79.	4905748	Liquefied Petroleum Gas	FG	1,258	1,258
80.	4920125	Hydrocyanic Acid	PA	1,226	1,226
81.	4941161	Maleic Anhydride	OA	1,168	1,195
82.	4905761	Methyl Chloride	FG	1,168	1,180
83.	4910320	Pulp Mill Liquid (F.L., n.o.s.)	FL	1,159	1,163
84.	4905711	Liquefied Petroeum Gas	FG	1,139	1,141

TABLE 11. (Continued)

Rank	STC Code	Commodity	Haz. Class	Total Tank Movements	Total Commodity Moves
85.	4921410	Aniline Oil, Liquid	PB	1,088	1,089
86.	4909160	Ethyl Acetate	FL	1,066	1,098
87.	4909129	Butyl Alcohol	FL	1,052	1,052
88.	4931405	Acrylic Acid	CM	1,031	1,050
89.	4908125	Carbon Bisulfide	FL	1,013	1,058
90.	4905703	Butadiene, Inhibited	FG	1,005	1,005
91.	4921445	Motor Fuel Antiknock Compound	PB	1,000	1,009
92.	4935220	Alkaline Liquid, n.o.s.	CM	975	1,244
93.	4930026	Hydrofluorisilicic Acid	CM	930	958
94.	4913194	Clycol Ethers, nec (C.L., n.o.s.)	CL	902	902
95.	4913144	formaldehyde Solution	CL	901	901
96.	4930026	Hydriodic Acid	CM	897	903
97.	4907223	Chllroprene, Inhibited	FL	889	889
98.	4908119	Butyraldehyde	FL	870	873
99.	4909159	Ethyl Alcohol	FL	867	872
100.	4963120	Dinitrotoluene, Liquid	OE	866	866
101.	4916456	Sodium Metal	FS	855	865
102.	4909131	Butyl Alcohol	FL	850	852
103.	4904552	Chlordifluoromethane	NG	795	881
104.	4907280	Vinylidene Chloride, Inhibited	FL	779	780
105.	4909117	Butyl Alcohol	FL	765	766
106.	4909166	Ethylene dichloride	FL	739	748
107.	4909128	Butyl Acetate	FL	715	724
108.	4940360	Napthalene	OA	709	715
109.	4909146	Ethyl Alcohol	FL	679	729
110.	4904503	Argon, Refrigerated Liquid	NG	679	679
111.	4905510	Dimethylamine, anhydrous	FG	664	665
112.	4910280	Resin Solution	FL	594	1,244
113.	4909267	Propyl Alcohol	FL	586	592
114.	4915320	Asphalt, cut back	CL	584	588
115.	4935248	Sodium Solution Waste (C.L., n.o.s.)	CM	583	586
116.	4909153	Chlorobenzene	FL	578	580
117.	4908162	Ethyl Chloride	FL	566	582
118.	4910490	Aromatic Concentrates (F.L., n.o.s.)	FL	555	557
119.	4904270	Hydrogen Chloride	NG	542	548
120.	4907255	Methyl Methacrylate Monomer, Inhibted	FL	535	536
121.	4932359	Phosphorus Trichloride	CM	522	531
122.	4909225	Methyl Butyrate	FL	517	521
123.	4909110	Amyl Acetate	FL	513	516
124.	4907230	Isoprene	FL	504	509
125.	4910282	Resin Solution	FL	493	634

- Pool Fires - Thermal Radiation Hazards, Toxic Combustion Products.

Quantitative analyses were then performed for each incompatible combination to determine the surface area around the derailment site in which the lethality threshold for each applicable consequence was surpassed. The surface area above the lethality threshold was then calculated for the specific (i.e. not mixed) chemicals in the binary combination. A "net" surface area was obtained by subtracting the highest surface area for the individual chemicals from the surface area for the mixture. The "net" surface area reflected the aggravation (or mitigation) of the consequences caused by mixing of the chemicals together. The combinations which had a net surface area in excess of 10,000 m^2 were then categorized into groups based on similarity in chemical structure or reactivity and a matrix of incompatible groups was developed.

The incompatible combinations were also rank ordered based on "risk" rather than the consequence-based ranking described above. The risk-based analysis incorporated the number of yearly tank car movements for each commodity along with the net surface area above the lethality threshold for each incompatible chemical combination. The tank car movements provided an indication of the frequency or potential for the chemicals mixing. The <u>relative</u> risks for each combination were then rank ordered and a risk-based matrix of incompatible groups was developed.

In completion of Task Item 2, a minimum segregation distance was estimated which would minimize or prevent the commingling of commodities during derailment accidents in which tank cars are ruptured.

A detailed description of the analyses procedures and results is given in the following Sections and Appendixes H through J.

3.1 Determination of Incompatible Binary Combinations

The compatibilities of the hazardous commodities were evaluated in binary combinations. Ternary or higher order combinations were not evaluated because the large number of combinations (e.g. 161,700 different ternary combinations) would make analyses impractical. There are 5151 different binary combinations for the 102 chemicals considered so a screening of the combinations was still required in order to reduce the number of combinations to a reasonable level prior to detailed evaluations. The first step in the screening process entailed arrangement of the chemicals into similar reactivity groups as shown in Figure 5. The basis for the groupings was an American Society for Testing and Materials (ASTM) chemical incompatibility guide [Ref. 6]. The compatibility of each group combination was then identified using the ASTM Hazardous Waste Incompatibility Chart [Ref. 6] shown in Figure 6. Those group combinations where a potential incompatibility exists were carried to the next step. Incompatible reactions considered included reactions that result in heat generation, fire, flammable gas generation, toxic gas generation, explosion, polymerization, or unknown consequences. Other consequences such as solubilization of toxic substances and innocuous gas generation were noted but not further considered because the hazards would be minimal when the chemicals are mixed in the open.

It is important to note that the U.S. Coast Guard has developed another version of a chemical reactivity matrix as shown in Figure 7 [Ref. 7]. The Coast Guard matrix was developed as a compatibility guide for bulk shipment of hazardous materials by water. The ASTM matrix was used as the screening basis instead of the Coast Guard matrix because the ASTM matrix provided a generally more detailed breakdown of chemical groups and identified types of consequences resulting from mixing incompatible chemicals (e.g. flammable gas generation,heat, etc.). A comparison of the chemical groups in the Coast Guard and ASTM matrices is given in Appendix H.

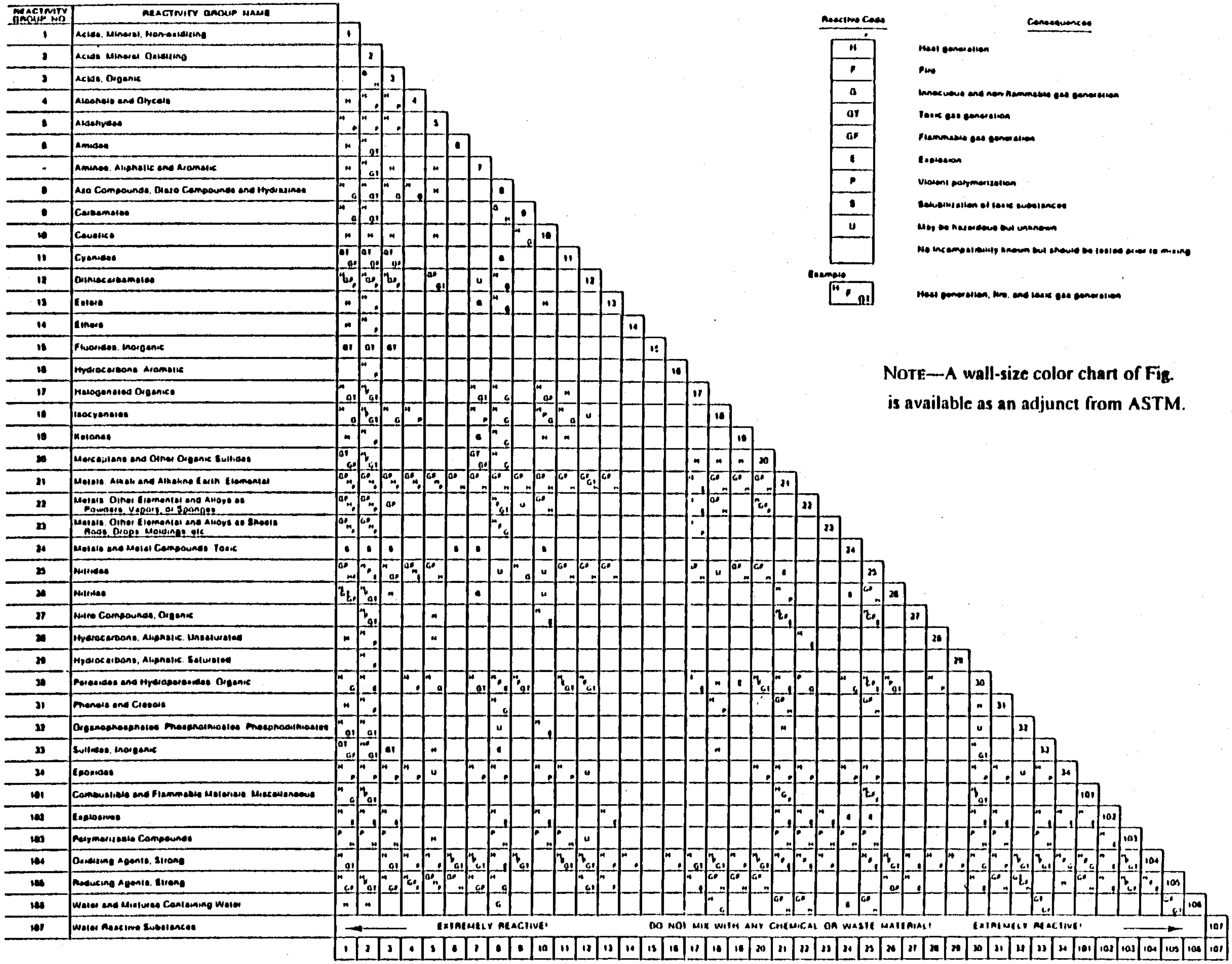
Specific chemical combinations were then identified for each set of chemicals within the incompatible groups. Literature was reviewed to characterize these specific combinations by the types of products formed, the nature of the reaction (e.g. none, slow, minimal, vigorous, or violent) and amount of heat generated during the reaction (e.g. minimal, none, excessive, etc.). Applicable references were identified through searches of the Chemical Abstracts Service (CAS) and National

Group 1 Non-Oxidizing Mineral Acids	Group 5 Aldehydes	Group 14 Ethers	Group 19 Ketones
Hydrochloric Acid Hydrocyanic acid Hydrofluorosilicic Acid Hydrogen Fluoride Hydroiodic Acid Phosphoric Acid	Acetaldehyde Butyraldehyde Formaldehyde Solution	Glycol Ethers	Acetone Methyl Ethyl Ketone
Group 2 **Oxidizing Mineral Acids**	**Group 7** **Aliphatic and Aromatic Amines**	**Group 16** **Aromatic Hydrocarbons**	**Group 20** **Mercaptans/Organic Sulfides**
Nitric Acid, Fuming Oleum Sulfuric Acid Sulfuric Acid, spent	Aniline Oil, Liquid Hexamethylene Diamine Sol.	Benzene Styrene Monomer, Inhibited Toluene Xylene	Carbon Disulfide
Group 3 **Organic Acids**	**Group 10** **Caustics**	**Group 17** **Halogenated Organics**	**Group 21** **Elemental Alkali Metals**
Acetic Acid, Glacial Acrylic Acid	Alkaline Liquid, n.o.s. Anhydrous Ammonia Potassium Hydroxide, Liq. Sodium Hydroxide, liq.	Carbon Tetrachloride Chloroprene, Inhibited Methyl Chloride Vinyl Chloride	Sodium Metal
Group 4 **Alcohols and Glycols**	**Group 13** **Esters**	**Group 18** **Isocyanates**	**Group 24** **Toxic Metals/Metal Compounds**
Alcoholic Beverage Butyl Alcohol Denatured Alcohol Ethyl Alcohol Isopropanol Methyl Alcohol Octyl Alcohol	Butyl Acrylate Ethyl Acetate Ethyl Acrylate, inhibited Methyl Methacrylate Monomer Vinyl Acetate	Toluene Diisocyanate	Motor Fuel Antiknock Comp.

FIGURE 5. CHEMICAL GROUPS BASED ON SIMILAR CHEMICAL STRUCTURE AND REACTIVITY

Group 26 Nitriles	Group 31 Phenols and Cresols	Group 104 Strong Oxidizing Agents	Miscellaneous Compounds
Acrylonitrile	Phenol	Chlorine Ferric Chloride Solution Hydrogen Peroxide Solution	Carbon Dioxide, Liquid Corrosive Liquid
Group 27 Organic Nitro Compounds	**Group 34 Epoxides**	**Group 105 Strong Reducing Agents**	
Dinitrotoluene	Ethylene Oxide Propylene Oxide	Phosphorus, Yellow or White Sulfur Dioxide	
Group 28 Unsaturated Hydrocarbons	**Group 101 Combustibles/Flammables**	**Group 106 Mixtures Containing Water**	
Butadiene Butadiene, Inhibited Liquefied Petroleum Gas(LPG) LPG - Butene LPG - Butylene LPG - Isobutylene LPG - Propylene	Coal Tar Distillate Combustible Liquid, n.o.s. Compound, Cleaning, Liquid Crude Oil Petroleum Distillate Fuel Oil Flammable Liquid, n.o.s. Fuel Oil Fuel, Aviation, Turbine Gasoline Gasoline, nec Oil Petroleum Naphtha Petroleum Residual Fuel Oil Petroleum, Partially Refined Pulp Mill Liquid	Ammonium Nitrate Solution	
Group 29 Saturated Hydrocarbons		**Group 107 Water Reactive Substances**	
Butane Cyclohexane Hexane LPG - Isobutane LPG - Propane		Acetic Anhydride Maleic Anhydride	

FIGURE 5. (Continued)



NOTE—A wall-size color chart of Fig. is available as an adjunct from ASTM.

FIGURE 6. ASTM HAZARDOUS MATERIAL INCOMPATIBILITY CHART

CARGO COMPATIBILITY

CARGO GROUPS \ REACTIVE GROUPS	1 NON OXIDIZING MINERAL ACIDS	2 SULFURIC ACID	3 NITRIC ACID	4 ORGANIC ACIDS	5 CAUSTICS	6 AMMONIA	7 ALIPHATIC AMINES	8 ALKANOLAMINES	9 AROMATIC AMINES	10 AMIDES	11 ORGANIC ANHYDRIDES	12 ISOCYANATES	13 VINYL ACETATE	14 ACRYLATES	15 SUBSTITUTED ALLYLS	16 ALKYLENE OXIDES	17 EPICHLOROHYDRIN	18 KETONES	19 ALDEHYDES	20 ALCOHOLS GLYCOLS	21 PHENOLS CRESOLS	22 CAPROLACTAM SOLUTION	
1 NON OXIDIZING MINERAL ACIDS		x			x	x	x	x	x	x	x	x	x			x	x						1
2 SULFURIC ACID	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2
3 NITRIC ACID		x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		3
4 ORGANIC ACIDS		x			x	x	x	x				x				x	x						4
5 CAUSTICS	x	x	x	x							x	x				x	x		x	x	x	x	5
6 AMMONIA	x	x	x	x						x	x	x	x			x	x		x				6
7 ALIPHATIC AMINES	x	x	x	x							x	x	x	x	x	x	x	x	x	x	x	x	7
8 ALKANOLAMINES	x	x	x	x							x	x	x	x	x	x	x		x				8
9 AROMATIC AMINES	x	x	x								x	x							x				9
10 AMIDES	x	x	x			x						x									x		10
11 ORGANIC ANHYDRIDES	x	x	x		x	x	x	x	x														11
12 ISOCYANATES	x	x	x	x	x	x	x	x	x	x										x		x	12
13 VINYL ACETATE	x	x	x			x	x	x															13
14 ACRYLATES		x	x				x	x															14
15 SUBSTITUTED ALLYLS		x	x				x	x															15
16 ALKYLENE OXIDES	x	x	x	x	x	x	x	x															16
17 EPICHLOROHYDRIN	x	x	x	x	x	x	x	x															17
18 KETONES		x	x				x																18
19 ALDEHYDES		x	x		x	x	x	x	x														19
20 ALCOHOLS GLYCOLS		x	x		x		x					x											20
21 PHENOLS CRESOLS		x	x		x		x			x													21
22 CAPROLACTAM SOLUTION		x			x		x					x											22
30 OLEFINS		x	x																				30
31 PARAFFINS																							31
32 AROMATIC HYDROCARBONS			x																				32
33 MISCELLANEOUS HYDROCARBON MIXTURES			x																				33
34 ESTERS		x	x																				34
35 VINYL HALIDES			x																			x	35
36 HALOGENATED HYDROCARBONS																							36
37 NITRILES		x																					37
38 CARBON DISULFIDE							x	x															38
39 SULFOLANE																							39
40 GLYCOL ETHERS		x										x											40
41 ETHERS		x	x																				41
42 NITROCOMPOUNDS					x	x	x	x	x														42
43 MISCELLANEOUS WATER SOLUTIONS		x										x											43
	1	.	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	

FIGURE 7. U.S. COAST GUARD HAZARDOUS MATERIAL INCOMPATIBILITY CHART

Technical Information Service (NTIS) data bases. The references are listed at the end of Appendix H.

Where literature information was unavailable, an organic and/or an inorganic chemist analyzed the combination and identified potential reactions, if any, as well as the rate of the reaction. It is important to note that literature information was unavailable for many of the combinations of interest. Chemical reaction references described some of the reactions but only under select conditions (e.g. dilute concentration, carefully controlled temperature, presence of a catalyst, etc.) which are inapplicable to the scenarios involved in the accidental mixing of bulk chemicals. In these cases the chemists reviewed the information and estimated whether or not similar reactions would occur when the chemicals were rapidly mixed in bulk quantities. In general, the bulk mixing scenarios result in severe consequences as compared with laboratory or industrial reactions because the lack of temperature control could allow the reaction to "run away", causing a potential fire or excessive evaporation of products and residual reactants.

Another reason for the lack of literature information is that the products from many of the combinations of interest would have no commercial value. Research on the reactions would have been only of academic interest and, as such, limited work would have been done. Of noted exception are studies given in References 8 and 9. In these studies, small quantities of chemicals were mixed together in binary combinations to determine their compatibility. Temperature and pressure rises were recorded and used to determine the hazard of the combination. Information from these references was incorporated into the binary chemical reactivity analysis.

The ASTM reactivity group combinations that were initially shown to be compatible were subsequently reviewed to determine if any incompatible combinations were overlooked. As a result of this review, several additional combinations were added to the list of incompatible chemicals. For example, mixing oleum or concentrated sulfuric acid (ASTM Chemical Reactivity Group No. 2) with aqueous solutions of either hydrochloric or hydrofluorosilicic acid (ASTM Chemical Reactivity Group No. 1) could generate a toxic cloud of hydrogen chloride or hydrogen fluoride, respectively. The ASTM chart given in Figure 6 identifies these combinations as compatible. It is important to note that a chemical reaction does not occur in these examples, but rather the hydrochloric or hydrofluorosilicic acid are physically displaced from solution as a result of the sulfuric acid being the stronger acid.

A summary of the chemical reactivity evaluations is given in Appendix H. There were 1337 individual combinations evaluated of which 127 were subsequently deemed to be compatible. The remaining 3814 combinations, primarily combinations of combustible materials (ASTM Chemical Reactivity Group 101) or aliphatic hydrocarbons (ASTM Chemical Reactivity Groups 28 and 29) with other organic chemicals were judged to be compatible, and were not evaluated further.

Combinations involving non-oxidizing mineral acids (ASTM Chemical Reactivity Group 1), oxidizing mineral acids (ASTM Chemical Reactivity Group 2), and caustics (ASTM Chemical Reactivity Group 10) dominated the list of incompatible chemicals -- non-oxidizing mineral acids were involved in 424 combinations (35 percent of the incompatible combinations), oxidizing mineral acids in 324 combinations (27 percent), and caustics in 179 combinations (15 percent).

3.2 Consequence Analyses

After the incompatible reactions were characterized, quantitative consequence analyses were performed to determine which combinations represent the greatest hazard and risk to the public. The consequences that were analyzed and their causes included:

- Toxic Emissions
  - Formation of volatile toxic reaction products.
  - Enhanced evaporation of residual chemicals as a result of heat generated during the reaction.

- Fire Balls

  - Formation of volatile and flammable reaction products which form a cloud which subsequently ignites.

  - Enhanced evaporation of residual chemicals as a result of heat generated during the reaction. If these chemicals are volatile and flammable then a vapor cloud could form which subsequently ignites.

- Unconfined Vapor Cloud Explosions (UVCE's)

  - Formation of volatile and flammable reaction products which form a cloud which subsequently ignites.

  - Enhanced evaporation of residual chemicals as a result of heat generated during the reaction. If these chemicals are volatile and flammable then a vapor cloud could form which subsequently ignites.

- Condensed Phase Explosions

  - A runaway reaction involving a chemical that has explosive properties such as concentrated hydrogen peroxide.

- Pool Fires

  - An exothermic reaction that causes the ignition temperature of one of the chemicals to be attained.

As shown in Appendix H, some combinations may result in multiple consequences. For example, the reaction of oleum with methyl alcohol (see page H-11) generates dimethyl ether and formaldehyde. Because significant heat would be generated in this reaction, residual SO_3 from the oleum could be volatilized (Toxic Emission Hazard). The dimethyl ether and formaldehyde products could also be vaporized during the course of the reaction (Toxic Emission, Fire Ball, and Unconfined Vapor Cloud Explosion Hazards). The reaction may also generate sufficient heat to cause ignition of the liquid (Pool Fire Hazard). It is important to note that a pool fire may lead to thermal radiation hazards to personnel, formation of toxic combustion products, and/or exposure of loaded (non-ruptured) tank cars of chemicals to a fire. In the latter case, the fire may cause the tank car to rupture following pressurization. The rupture could cause the tank car to "rocket" as has been observed in several previous accidents described in Section 2.3.

The assumptions and calculation procedures for these consequences are discussed in the following sections.

3.2.1 Assumptions and Basis for the Consequence Analysis

A review of previous accidents (discussed in Section 2.3) indicated a wide variance in conditions are possible when tank cars rupture following a derailment. Several site-specific parameters must be known in order to perform the consequence analysis. These include:

- Quantity of each chemical spilled
- Quantity of each chemical spilled that mixes and the degree of mixing
- Actual temperature rise resulting from the chemical reaction
- Surface area and average depth of the spill
- Ambient temperature, wind speed and atmospheric stability conditions
- Mitigation measures including fire-fighting to mitigate pool fires, spreading a foam or adsorbent on the spill to mitigate vaporization of toxic chemicals, and absorption of the chemicals into the soil or water.

It is evident that accurate specification of the above parameters to cover all possible derailment scenarios is not possible. However, a single scenario could be specified and <u>relative</u>, rather than absolute, consequences could be calculated. This approach would still allow the worst case combinations to be identified, but would not allow the results of the consequence analyses to be used for other purposes such as determining evacuation distances from the derailment site. The selected scenario was based on previous derailment accidents as much as possible and involved the following conservative, yet realistic, assumptions:

- Two tank cars, each of 100 ton capacity (200,000 pounds), are ruptured in a derailment accident.

- The contents of the tank cars instantly mix and form a circular pool 100 meters in diameter (7854 m^2 surface area).

- There is no mitigation of the accident.

- The reaction consumes about 10 to 25 percent of the chemicals when one of the chemicals is volatile (i.e. vapor pressure greater than 1/2 atmosphere at ambient conditions). A 25 percent reaction was assumed for chemicals that are soluble or miscible in one another.

- The reaction consumes about 50 to 75 percent of the chemicals when both of the chemicals are non-volatile (i.e. vapor pressure less than 1/2 atmosphere at ambient conditions).

- The reaction consumes about 50 percent of the chemicals when both of the chemicals are volatile - reaction in both the liquid and gas phase.

- The reaction consumes about 10 percent of the chemicals when one of the chemicals is a solid.

- The heat of reaction causes enhanced evaporation of residual (i.e. non-reacted) chemicals. A 25°C temperature rise was assumed if 10 to 50 percent of the chemicals reacted while a 75°C temperature rise was assumed if 50 to 75 percent of the chemicals reacted. Specification of the temperature rise was based on the nature of the reaction as given in Appendix H (i.e. slow, violent, etc.).

These assumptions served as the basis for the consequence calculations discussed in the subsequent sections.

3.2.2 Determination of Consequences Resulting from Toxic Emissions

Toxic chemical releases can result from formation of a toxic reaction product that is volatile and/or from enhanced evaporation of residual or unreacted chemicals caused by heat generated during an exothermic chemical reaction. The release of the toxic chemicals can either be continuous (i.e. a plume) as in the case of evaporation of relatively non-volatile chemicals from a liquid pool or instantaneous (i.e. a puff) as in the case of rapid formation of a gas or evaporation of volatile chemicals from a liquid pool. Based on previous studies, it was assumed that a continuous release occurs when the vapor pressure of the chemical is less than about 400 mm Hg. An instantaneous release was assumed when the vapor pressure of the chemical exceeds about 400 mm Hg.

The emission rates for a continuous release of toxic chemicals from a liquid pool were estimated by the following equation [Refs. 10, 11]:

$$Q_i = \frac{K_{gi}\ A\ P_i\ X_i\ M_i}{RT} \qquad (3\text{-}1)$$

where
- Q_i = evaporation rate of component i (g/sec)
- K_{gi} = mass transfer coefficient of component i (m/sec)
- A = area of the spill = 7854 m^2
- P_i = vapor pressure of component i (mm Hg)
- M_i = molecular weight of component i (g/gm mole)
- R = 0.06236 m^3 mm Hg/gm mole/°K
- T = temperature = 298°K (25°C)

The mass transfer coefficient was estimated from:

$$K_{gi} = 0.0048\ (U)^{0.78}\ (D)^{-0.11}\ (S_c)^{-0.67} \qquad (3\text{-}2)$$

where:
- U = wind velocity (m/sec) - assumed to be 5 m/sec
- D = diameter of the spill = 100 m
- Sc = Schmidt Number
  - For molecular weight < 100, $(S_c)^{-0.67} \approx 0.7$
  - For molecular weight between 100-200, $(S_c)^{-0.67} \approx 0.6$
  - For molecular weight > 200, $(S_c)^{-0.67} \approx 0.5$

In the case of an instantaneous release, it was assumed that the chemical(s) would be instantly released at the location of the spill. A tabulation of release type (continuous or instantaneous) and release rates for the chemicals of interest (excluding reaction products) is given in Appendix I. This tabulation includes not only the release rates at ambient temperature but also those where the reaction raises the temperature to 50 or 100°C from an ambient temperature of 25°C.

Dispersion of the toxic chemicals was modeled using a "simple gas" model with the following assumptions:

- The diffusing vapor is neutrally buoyant
- Mixing with air is uniform throughout the vapor cloud
- The calculated concentration is time-averaged
- The wind is uniform throughout the vertical extent of the cloud at a speed of 5 m/sec
- The terrain is flat (i.e. no wake effects)
- There is no depletion of the puff/plume through deposition or reaction with atmospheric components (i.e. water vapor)
- The spill occurs at night.

The simple gas dispersion equations for a continuous release are:

$$C = \frac{Q}{2\ \sigma_\theta X\ \sigma_\Phi X\ U} \qquad \text{when} \quad \sigma_\Phi X < z \qquad (3\text{-}3a)$$

or

$$C = \frac{Q}{2\ \sigma_\theta X\ z\ U} \qquad \text{when} \quad \sigma_\Phi X \geq z \qquad (3\text{-}3b)$$

where:
C = concentration of the vapor at distance x (mg/m^3),
Q = emission rate (mg/sec)
σ_θ = horizontal fluctuation = 0.09,
X = downwind distance (meters),
σ_Φ = vertical fluctuation = 0.06,
U = wind speed = 5 m/sec

z = mixing layer height = 300 meters.

In the case of an instantaneous release, the simple gas dispersion equation is:

$$C = \frac{2W}{(2\pi)^{3/2}\ (\sigma_\Phi X)^2\ z} \qquad (3\text{-}4)$$

where: C = concentration of the vapor at distance x (mg/m^3),
W = total mass released (mg)
X = downwind distance (meters),
σ_Φ = vertical fluctuation = 0.06,
z = mixing layer height = 300 meters.

The distance obtained from the dispersion calculations served as a check on whether a release is instantaneous or continuous for borderline cases (i.e. vapor pressure of 300 to 500 mm Hg). An instantaneous release was assumed when the distance to the critical concentration obtained from the dispersion calculations divided by the wind speed (5 m/sec) is less than 100. The dispersion calculations determined the down wind distance to a critical concentration. The critical concentration for this study was assumed to be the Immediately Dangerous to Life and Health (IDLH), which is the maximum concentration from which one could escape within 30 minutes without any irreversible health effects. Although the IDLH is generally not a lethal limit, it was used instead of a more accurate time-weighted lethal dose because of the availability of data. Time dependent toxicity data for all of the chemicals of interest is generally unavailable, whereas IDLH concentrations are readily available from sources such as NIOSH [Ref. 12]. A tabulation of IDLH levels for the chemicals of interest is given in Appendix I. The IDLH values for several potentially toxic chemicals were not available in the literature including:

- Acrylic acid
- Butyl acrylate

- Hydriodic acid
- Maleic anhydride
- Vinyl acetate
- Vinyl chloride.

In these cases the toxic emission consequences could not be calculated. It is also important to note that there may be a synergism in toxicity effects following exposure to multiple chemicals. Because of the lack of toxicity data, the synergism of toxic effects was not considered in this study.

Because many of the chemicals under consideration are in themselves quite toxic, the dispersion of the chemicals resulting from a spill where the chemicals are not mixed was also modeled. This was done in order to determine the difference in consequences between chemicals that mix following a spill and the same chemicals that do not mix following a spill. In several cases, the mixing of the chemicals would actually reduce the consequences as compared with the unmixed chemicals.

Results of the dispersion calculations are given in Appendix I.

3.2.3 Determination of Consequences Resulting from Fireballs

Fireballs are caused by ignition of a cloud of flammable vapor resulting in a thermal radiation hazard. The amount of the material in the vapor cloud is relatively small (i.e. less than a few tons) so the cloud burns rather than explodes following ignition. The flammable gas cloud can form as a reaction product and/or from enhanced evaporation of the chemicals caused by heat generated during a chemical reaction. If the flammable gas was formed as a reaction product, then an instantaneous release was assumed as in the case of chemicals with high vapor pressures.

The calculation method for determining the thermal radiation hazards from a fireball first involved determining the amount of flammable gas in the cloud. The radiant flux and duration of the fireball were then calculated. It was assumed that the duration of the fireball equaled the exposure time (i.e. length of time an individual would be exposed to the thermal radiation). No credit was taken for obstructions such as trees or buildings which would block the thermal radiation, thereby mitigating the consequences. An empirical equation was then used to estimate the distance from the edge of the fireball where the radiant flux would be lethal for the estimated exposure time. This distance was added to the radius of the fireball to give an overall distance above the lethal limit.

For a continuous release of vapor, the amount of flammable vapor above the lower flammability limit under "D" neutral atmospheric stability is given by [Ref. 13]:

$$W_{flam} = \frac{2.1\ T_o\ (w/U)^{1.6}}{(M\ L)^{0.6}} \qquad (3\text{-}5)$$

where:
- W_{flam} = amount of vapor in the cloud above the flammable limit (kg),
- T_o = ambient temperature = 298°K,
- w = release rate (kg/sec),
- U = wind speed = 5 m/sec,
- M = molecular weight (g/gm mole),
- L = lower flammable limit (volume percent).

The radiant flux from a fireball was estimated from [Ref. 14]:

$$Q = \frac{f\ H_c\ W_{flam}\ a}{4\ \pi\ X^2\ t_d} \qquad (3\text{-}6)$$

where:
- f = fraction of combustion energy converted to radiant energy ≈ 0.2 for chemicals containing oxygen atom(s) or ≈ 0.4 for other chemicals,
- H_c = heat of combustion (kJ/kg),
- a = transmissivity of the atmosphere ≈ 0.75 (over a distance of 50 meters)
- X = distance from edge of fireball (meters),
- t_d = duration of fireball (sec).

The duration of the fireball was calculated from [Ref. 15]:

$$t_d = 0.923(W_{flam})^{0.303} \qquad (3\text{-}7)$$

The radiant flux which would be lethal to 50 percent of the population (i.e. LD_{50}) is given by [based on data in Ref. 16]:

$$LD_{50} \text{ Radiant Flux } (kw/m^2) = \exp(6.4 - 0.80 \ln(t_d)) \qquad (3\text{-}8)$$

The edge of the fireball or radius of the fireball was calculated from [Ref. 13]:

$$\text{Radius} = 0.34 \left[\frac{w\ T_o}{M\ (L\ S_t)^{\frac{1}{2}}}\right]^{0.33} \qquad (3\text{-}9)$$

where: S_t = stoichiometric concentration (volume percent),
Radius = radius of fireball (meters).

The equations given above were combined to estimate the distance from the fireball to the LD_{50} limit for continuous releases. A similar set of equations was used to calculate the thermal radiation hazards from a fireball formed by an instantaneous release except the amount of flammable vapor above the lower flammability limit and the cloud radius were calculated from [Ref. 13]:

$$W_{flam} = W_t \left(1 - \exp\left(\frac{-\ 0.36}{(L)^{0.6}}\right)\right) \qquad (3\text{-}10)$$

where: W_t = total amount of vapor released (kg).

$$\text{Radius} = 0.34 \left[\frac{W_t\ T_o}{M\ (L\ S_t)^{\frac{1}{2}}}\right]^{0.33} \qquad (3\text{-}11)$$

Results of the fireball calculations are given in Appendix I. It is important to note that fireballs were not considered for combinations in which one of the chemicals is a non-flammable gas (i.e. hydrogen fluoride). For these cases, it was assumed that even if a flammable gas is formed in a reaction that the presence of the non-flammable gas would prevent ignition of the cloud. Exceptions are cases involving chlorine and a flammable vapor. In these cases, the flammable chemical may "burn" by reaction with the chlorine.

3.2.4 Determination of Consequences Resulting from Unconfined Vapor Cloud Explosions (UVCE's)

UVCE's are caused by ignition of a large unconfined cloud of flammable vapor leading to an explosion which causes blast pressure hazards. Although relatively high over-pressures are required to cause fatalities (e.g. over 10 psi), the explosion may form lethal projectiles at much lower pressures when, for example, the explosion damages or destroys adjacent structures. A vapor cloud would require at least several tons of flammable vapor in order to have the potential for an explosion rather than the deflagrative burning (i.e. fireball) associated with smaller sized clouds. In a UVCE the energy is released in a very short period because of the high flame speed in the cloud. Fireballs, on the other hand, have low flame speeds so the energy is gradually released causing little or no blast pressure.

The calculation method for determining the blast hazards from a UVCE first involved determining the amount of flammable gas in the cloud. The theoretical TNT equivalent for the cloud was then calculated. Because the explosion will not consume all of the vapor in the cloud, an empirical equation was used to estimate the efficiency of the explosion. The explosion efficiency was multiplied by the theoretical TNT equivalent to obtain the expected TNT equivalent. The distance to a "side-on" or incident over-pressure of about 2.0 psi was then estimated using an iterative approach. The 2.0 psi over-pressure was selected as the lethal limit below which the likelihood of projectile formation leading to a lethality is minimal.

The amount of flammable vapor above the lower flammability limit in the cloud was estimated by the correlations given in Section 3.2.3. The theoretical TNT equivalent was calculated from [Ref. 13]:

$$TNT_t = \frac{W_{flam} H_c}{4186} \tag{3-12}$$

where: TNT_t = Theoretical TNT equivalent (kg TNT),
W_{flam} = Weight of flammable material in the cloud (kg),
H_c = Heat of combustion kJ/kg.

If $TNT_t < 1{,}000{,}000$ then the explosion efficiency was estimated from the following equation [Ref. 13]:

$$\text{Efficiency} = 0.5[1- \sqrt{}(1 - \exp\{-0.31\ [\ln(W_{flam}/1{,}000{,}000)]^2\})] \tag{3-13a}$$

If $TNT_t > 1{,}000{,}000$ then:

$$\text{Efficiency} = 0.5[1+ \sqrt{}(1 - \exp\{-0.31\ [\ln(W_{flam}/1{,}000{,}000)]^2\})] \tag{3-13b}$$

The actual TNT equivalent is:

$$TNT_a\ (\text{kg TNT}) = TNT_t * \text{Efficiency} \tag{3-14}$$

This was then used to estimate the incident pressure by the following equation [Ref. 13]:

$$P_{so} = 14.696\ \{3.9/[X\ V_d/\ (TNT_a)^{0.33}]^{1.85}\ \ + 0.5\ (TNT_a)^{0.33}\} \tag{3-15}$$

where: P_{so} = Side-on or incident over-pressure (psi),
X = Distance from the UVCE (meters),
V_d = Virtual distance in meters = $0.25 \sqrt{}(W_{flam})$.

Iterations were performed by varying the distance until P_{so} was nearly equal to 2.0. Results of the UVCE calculations are given in Appendix I.

3.2.5 Determination of Consequences from Condensed Phase Explosions

Condensed phase explosions can occur when an unstable chemical such as a peroxide is heated, shocked or ignited. The chemical can undergo an exothermic decomposition reaction at extremely fast rates to produce gaseous reaction products at high temperature and pressure. The rapid heat release causes the surrounding air to expand resulting in a shock or blast wave with consequent over-pressures. The chemical combinations which can lead to a condensed phase explosion include:

- Chemicals which exothermically react with concentrated hydrogen peroxide. The heat released may cause the residual hydrogen peroxide or the reaction product (e.g. organic peroxide) to explode.
- Chemicals which exothermically react with dinitrotoluene. The heat released may cause the residual dinitrotoluene to explode.
- Combinations of chlorine and alcohols which result in the formation of unstable alkyl hypochlorites.
- Combinations of fuming nitric acid with alcohols, aldehydes, organic acids, anhydrides, aromatic hydrocarbons, or acrylonitrile which lead to unstable organic nitro or organic nitrate compounds.
- Reactions of chlorine, oleum, concentrated sulfuric acid or phosphorus with ammonium nitrate solution which may lead to an explosion in the residual ammonium nitrate.
- Reactions of dinitrotoluene with caustics or sulfuric acid which may lead to the formation of unstable compounds.

The explosion calculations were based on the "TNT Equivalence" method. The heat of decomposition of the unstable compound was either obtained from the literature or estimated from the heats of formation of the compound and its decomposition products. The heat of decomposition was then converted to a TNT equivalent by dividing by the heat of decomposition of TNT (454 kcal/lb of TNT). The scaled ground distance for an incident over-pressure of 2 psi (assumed to be the lethal limit as in the case of a UVCE) was obtained for a hemispherical TNT surface explosion at sea level [Ref. 17]. The distance to a 2 psi over-pressure from the center of the explosion was then found from:

$$X = Z_g * (TNT_e)^{1/3} \tag{3-16}$$

where: X = distance to 2 psi over-pressure (feet),
Z_g = scaled ground distance ($ft/lb^{1/3}$),
TNT_e = TNT equivalent (lbs of TNT).

Results from the condensed phase explosion calculations are given in Appendix I.

3.2.6 Determination of Consequences from Pool Fires

Pool fires are burning pools of liquids which can cause thermal radiation hazards to nearby personnel, down-wind toxic emission hazards from toxic combustion products or exposure of full tank cars to the heat of the fire. Many of the chemicals of interest are highly flammable and can be easily ignited by heat, sparks or flames. Several of the chemicals have the NFPA (National Fire Protection Agency) Flammability Hazard of 4 (highest flammability rating) including:

- Acetaldehyde
- Butadiene (inhibited and uninhibited)
- Butane
- Ethylene Oxide
- Hydrocyanic Acid
- Liquefied Petroleum Gas (All forms)
- Methyl Chloride
- Propylene Oxide
- Vinyl Chloride.

Two of the chemicals (Sodium metal and Phosphorus) are pyrophoric in that ignition may occur upon exposure to air. Also, pool fires may be initiated by highly exothermic reactions including:

- Chlorine in combination with most organic chemicals
- Oleum or concentrated sulfuric acid in combination with most organic chemicals
- Hydrogen peroxide in combination with aldehydes, unsaturated hydrocarbons, ketones or alcohols
- Sodium metal in combination with aldehydes, organic acids, alcohols, esters, acrylonitrile, epoxides, or chlorinated hydrocarbons.

The calculation procedure for thermal radiation hazards is discussed as follows. The diameter of the pool fire was assumed to be equivalent to the diameter of the spill (i.e. 100 meters). The flame height and flame tilt caused by the wind were calculated by correlations given in References 16 and 18. The amount of radiant heat at the flame surface was then estimated as follows:

$$Q = \frac{f\ H_c\ W_{flam}\ v_f}{\pi\ d\ (ht + d/4)} \tag{3-17}$$

where:

Q	=	radiant flux (kw/m^2),
f	=	fraction of combustion energy converted to radiant energy $\approx$ 0.2 for chemicals containing oxygen atom(s) or $\approx$ 0.4 for other chemicals,
H_c	=	heat of combustion (kJ/kg),
v_f	=	burn rate $\approx$ 0.095 cm/sec,
d	=	diameter of pool fire = 100 meters,
ht	=	height of the flame (meters).

A correlation of distance versus atmospheric transmissivity was developed assuming absorption of the radiant heat by water vapor (50% relative humidity) and carbon dioxide (partial pressure = 0.0003 atmospheres). View factors for up-wind, down-wind, and cross-wind directions from the fire were calculated using the procedure given in Reference 19. The thermal radiation levels at 5 meter intervals from the fire were then calculated from the radiant energy, atmospheric transmissivity and view factors for up-wind, down-wind, and cross-wind directions. The calculations were repeated until the thermal radiation decreased to below the lethal limit. The time-dependent lethal limit for thermal radiation was assumed to be 10 kw/m^2 for a one minute exposure [Refs. 16, 20].

Results of these calculations indicate that the down-wind distance (worst case) to the lethal radiant flux of 10 kw/m^2 is about 30 meters or less for the chemicals of interest. This is insignificant as compared with the other hazards such as toxic emissions, fireballs, etc.

The second potential consequence from pool fires is the formation of toxic combustion products. Examples of toxic combustion products and their sources include:

- NO_x (nitrogen oxides) from combustion of chemicals containing a nitrogen atom such as hydrocyanic acid, acrylonitrile, ammonia, aniline, hexamethylene diamine solution, toluene diisocyanate, dinitrotoluene, or ammonium nitrate solution. NO_x may also be formed in fires initiated by the reaction of fuming nitric acid with an organic chemical.

- SO_2 (sulfur dioxide) from combustion of chemicals containing a sulfur atom such as carbon disulfide. SO_2 may also be formed in fires initiated by the reaction of oleum or concentrated sulfuric acid and an organic chemical.

- HCl (hydrogen chloride) and $COCl_2$ (phosgene) from combustion of chemicals containing a chlorine atom such as chloroprene, vinyl chloride, or methyl chloride. HCl and $COCl_2$ may also be formed in fires initiated by the reaction of chlorine with an organic chemical.

- PCl_3 (phosphorus trichloride) from combustion of phosphorus in an atmosphere of chlorine.

- P_2O_5 (phosphorus pentoxide) from combustion of phosphorus in air. The P_2O_5 was assumed to turn into a mist of phosphoric acid as it reacts with water vapor in the air.

The calculation procedure for determining the consequences of toxic combustion products from pool fires is given as follows. Assumptions used in the calculations included:

- Average burn rate of about 5 mm/min (ranges from about 2 to 7 mm/min) [Ref. 7],
- 100 meter diameter pool fire (7854 m^2 area),
- Average density of 1000 kg/m^3,
- Average heat of combustion of 5560 cal/gm (10,000 BTU/lb),
- 100 tons (90,720 kg) of material involved in the pool fire,
- A wind speed of 5 m/sec,
- The rate of toxic combustion product formation is uniform during the course of the fire.

The mass burn rate and duration of the fire are:

$$5 \text{ mm/min} / 1000 \text{ mm/m} * 7854 \text{ m}^2 * 1000 \text{ kg/m}^3 = 39{,}270 \text{ kg/min}$$

$$90720 \text{ kg} / 39{,}270 \text{ kg/min} = 2.3 \text{ min}$$

The release of the toxic combustion products was assumed to be instantaneous because of the short duration of the fire. Unlike the evaporation of chemicals from a liquid pool, the toxic combustion products will be lifted into the air by the buoyant effects caused by the heat of the fire. As such, the dispersion modeling cannot assume a ground level release but rather an elevated release. An "effective release height" can be calculated which considers buoyant effects of the fire. The following equation, which assumes neutral atmospheric stability conditions, was used [Ref. 21]:

$$\Delta h = 4.8 \frac{(Q_h)^{0.26}}{(U)^{0.76}} \qquad (3\text{-}18)$$

where: Δh = effective release height (meters),
Q_h = heat output of the fire (cal/sec)
= 5560 cal/gm * 39,720 kg/min / 60 sec/min,
U = wind velocity = 5 m/sec.

The dispersion of the toxic combustion products was modeled by a two-dimensional Gaussian dispersion model that assumed the toxic combustion products were released at an elevation of 432 meters above the pool fire. The concentrations were calculated for various down wind distances. The results indicated that the down wind concentration does not surpass the IDLH level for any of the pool fires. The worst case, shown in Figure 8, is for a fire that forms toxic hydrogen chloride (HCl). In this case, the Threshold Limiting Value (TLV)) is exceeded butthe IDLH level is not. Thus, toxic combustion products from pool fires of chemicals of interest in this study do not appear to represent a lethal hazard and, as such, were not considered further.

Exposure of full tank cars to the heat of a pool fire may lead to their rupture as has been observed in the past. The rupture may cause the tank car to "rocket" or fragment, thereby exposing personnel and equipment to metal projectiles. A second consequence of a tank car rupture may result in explosive boiling of the released liquid if the chemical in the tank car is a liquefied gas. This phenomenon is known as a BLEVE or Boiling Liquid Expanding Vapor Explosion which results in blast or over-pressure effects similar to a condensed phase explosion.

Because a tank car explosion would be an indirect consequence of mixing incompatible chemicals, calculations were only performed to determine which of the chemicals of interest represents the greatest hazard. Results from the calculations were not included in the rankings of incompatible reactions. The procedure for determining the consequence of a tank car explosion was based on Reference 22. It was assumed that the rail tank car would be 40 percent full at the time of rupture [Ref. 23]. Results are given in Appendix I.

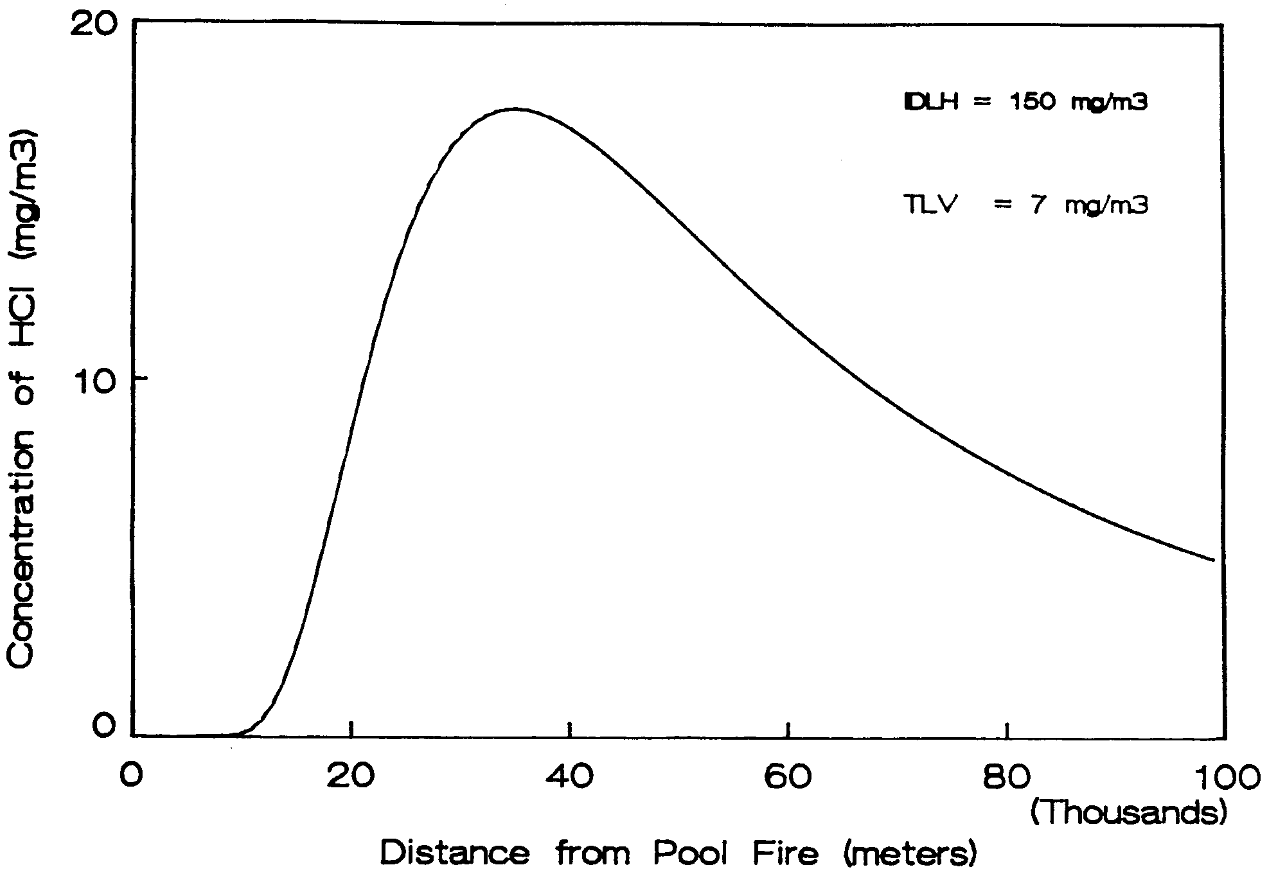


FIGURE 8. PLOT OF CONCENTRATION OF HYDROGEN CHLORIDE VERSUS DOWNWIND DISTANCE FROM A POOL FIRE INVOLVING HALOGENATED CHEMICALS

3.3 Rankings of Incompatible Chemical Combinations

Consequence-based and risk-based rankings of the incompatible chemical combinations were prepared to determine the worst case combinations. The consequence-based ranking determined which combinations had the worst consequences. The risk-based ranking, on the other hand, included a relative frequency with the consequence. The frequency is related to how often the two chemicals could be involved in the same derailment accident. A relative frequency was obtained using the yearly number of tank car movements for each chemical of the combination. This, of course, assumes movements are uniformly distributed in traffic and does not address concentration of movements on specific routes.

3.3.1 Consequence-Based Rankings

The first step in determining the rankings was calculating the surface areas above the lethal limits. The surface areas were based on the distances obtained in Section 3.2, assuming the following shapes for each consequence:

- Toxic emissions -- ellipse with the major axis equal to the distance calculated from the dispersion analysis and a minor axis equal to 1/10 the major axis distance (based on experience).
- Fireballs, UVCE's, and condensed-phase explosions -- circle with a radius equal to the distance calculated from the respective analyses.

Toxic emissions, fireballs, etc. may occur following a derailment, even without mixing of incompatible chemicals. As such, the surface area above the lethal limit for the unmixed chemicals of a binary combination was calculated and subtracted from the surface area obtained from the mixed chemicals to give a "net" surface area. In doing so, the effect of mixing on the consequences can be determined. The unmixed chemical which had the largest area was used in the subtraction. Results are given in Table J1 of Appendix J. Spills of single chemicals are provided in Table J2 for comparison.

The rankings, sorted by total surface area, are given in Table J3 of Appendix J. The total surface area represents the added areas of the toxic emission, fireball, UVCE and condensed-phase explosion consequences for each binary chemical combination (where applicable). The areas for the different consequences were added in order to penalize those combinations where more than one consequence is possible. The worst case combination was hydrofluorosilicic acid with sulfuric acid, where the highly toxic hydrogen fluorde is displaced from solution by the stronger sulfuric acid. If these chemicals are spilled but do not mix, then the consequences are negligible. As shown in Table J4 of Appendix J, the following combinations dominate the list:

- Oleum with organic chemicals -- Toxic emission, fire ball, UVCE consequences
- Fuming nitric acid with organic chemicals -- Toxic emission, fire ball, UVCE consequences
- Hydrogen peroxide with organic chemicals -- Toxic emission and condensed-phase explosion consequences
- Sodium metal with commodities containing water -- Fire ball and UVCE consequences
- ASTM Group 1 (Non-oxidizing mineral acids) with ASTM Group 2 (Oxidizing mineral acids) -- Toxic emission consequences.

The combinations which had an area of 10,000 m^2 or greater were categorized into their ASTM chemical reactivity groups. A matrix of incompatible groups was developed (shown in Figure 9) which represents most of the these combinations. Several combinations were omitted from the matrix because their ASTM groups had generally low consequences. The specific combinations that were excluded from the matrix include:

- Hydriodic acid with glycol ethers or phosphorus
- Styrene with ASTM Group 1 acids or ASTM Group 10 caustics

Group	ASTM Reactivity Group																											
1	Non-oxidizing mineral acids	1																										
2	Oxidizing mineral acids	x	2																									
3	Organic acids		x	3																								
4	Alcohols and glycols	x	x		4																							
5	Aldehydes	x	x	x	x	5																						
7	Aliphatic and aromatic amines		x	x		x	7																					
10	Caustics	x	x	x		x		10																				
13	Esters	x	x					x	13																			
14	Ethers		x							14																		
16	Aromatic hydrocarbons		x								16																	
17	Halogenated organics	x	x				x	x				17																
18	Isocyanates	x	x	x	x	x	x	x					18															
19	Ketones	x	x					x						19														
20	Mercaptans and organic sulfides														20													
21	Elemental alkali metals	x	x	x	x	x	x	x	x				x	x	x	21												
24	Toxic metal compounds	x	x														24											
26	Nitriles	x	x	x			x	x								x		26										
27	Organic nitro compounds		x			x		x								x			27									
28	Unsaturated aliphatic hydrocarbons		x																	28								
29	Saturated aliphatic hydrocarbons		x																		29							
31	Phenols and cresols		x															x				31						
34	Epoxides		x																				34					
101	Combustibles and flammables		x																					101				
104	Strong oxidizing agents		x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x		x	x	x	104			
105	Strong reducing agents		x					x											x						x	105		
106	Mixtures containing water		x													x											106	
107	Water reactive substances	x	x	x			x	x																	x			107

"X" = Incompatible Groups

FIGURE 9. MATRIX OF INCOMPATIBLE CHEMICAL GROUPS BASED ON CONSEQUENCE RANKING

- Hydrogen peroxide with hydrocyanic acid or hydrochloric acid
- Phosphorus with hydrochloric acid or ammonium nitrate solution
- Carbon disulfide with nitric acid, carbon tetrachloride, or propylene oxide
- Chloroprene with organic acids
- Sodium metal with styrene, acetic anhydride, carbon tetrachloride, or pulp mill liquid
- Motor fuel antiknock compound with chloroprene, aniline, or anhydrous ammonia
- Chlorine with ammonium nitrate solution, hydrochloric acid, hydrocyanic acid, or anhydrous ammonia
- Butyraldehyde with phenol
- Dinitrotoluene with acetic anhydride.

Two incompatible combinations within one ASTM group were identified:

- Fuming nitric acid with oleum - both in ASTM Group 2
- Hydrogen peroxide solution with ferric chloride solution - both in ASTM Group 104.

It is interesting to note that mixing of chemicals will generally mitigate the toxic emission consequences of highly toxic chemicals such as hydrocyanic acid, chlorine, anhydrous ammonia, and hydrogen fluoride. An exception is the combination of hydrocyanic acid with chlorine, which may form cyanogen chloride, a tear gas. In the case of hydrogen fluoride, all combinations resulted in either the same or reduced consequences as compared with the unmixed chemicals.

Similarly, mixing will generally mitigate the consequences (fireballs and UVCE's) of highly flammable chemicals including hydrocyanic acid, acetaldehyde, and ethylene oxide.

3.3.2 Risk-Based Rankings

An estimate of the relative risk of the incompatible combinations was determined by multiplying the areas from the consequence-based analysis by the yearly number of tank car movements of each chemical in the combination. The yearly tank car movements give an indication of the potential frequency for the chemicals being involved in the same derailment assuming a uniform distribution of tank cars over all train consists during a year. A normalized risk was then obtained by dividing the risk of each combination by the risk of the lowest contributor, which in this case was the combination of hydriodic acid with acrylic acid. The combination of hydriodic acid and acrylic acid would thereby have a normalized risk equal to one. All other combinations would have a normalized risk relative to how much greater the risk is than hydriodic acid with acrylic acid. A rank ordering of the chemical combinations by risk, given in Table J5 in Appendix J indicates that the combination of hydrochloric acid with sulfuric acid has the greatest risk -- over five orders of magnitude greater than hydriodic acid with acrylic acid. Over 50 percent of the risk is represented by the following combinations:

- Oleum with sodium hydroxide, methyl alcohol, denatured alcohol or fuel oil
- Sulfuric acid with hydrochloric acid, methyl alcohol, denatured alcohol, vinyl chloride, hydrofluorosilicic acid, carbon tetrachloride or benzene
- Sodium hydroxide with styrene, acetic acid or carbon tetrachloride
- Chlorine with anhydrous ammonia or hydrocyanic acid.

It is interesting to note that fuming nitric acid combinations do not appear as high in the risk-based ranking as they do in the consequence-based ranking. This is because of the low number of tank car moves per year for nitric acid (441/yr) as compared with the other commodities results in a lower potential frequency that nitric acid would be involved in a derailment.

A ranking of specific chemicals by risk, given in Table J6 of Appendix J, indicates that combinations involving sulfuric acid, oleum, sodium hydroxide and hydrochloric acid account for over 50 percent of the risk. Several organic compounds such as methyl alcohol appear near the top of this list primarily as a result of combinations with the aforementioned mineral acids and caustics.

A ranking of ASTM Group combinations is given in Table J7 of Appendix J. These were used to develop the risk-based incompatibility matrix shown in Figure 10.

3.4 Minimum Segregation Distance Between Tank Cars

The minimum segregation distance is the spacing distance between HAZMAT rail tank cars which is required to prevent mixing of incompatible chemicals during train accidents involving derailments. A precise specification of this distance cannot be made because of the following factors:

- Drainage ditches or culverts may be adjacent to the derailment site, which would allow mixing if two tank cars spilled regardless of the segregation distance
- Sloping of the terrain or presence of bodies of water (i.e. lakes or streams), which would significantly impact the potential for and degree of mixing, cannot be adequately generalized because of the wide variance in possible conditions
- Surface adsorption of liquids will depend on the soil type (e.g. clay, sand, gravel) and on the presence of relatively impermeable concrete or asphalt.

In considering these factors it becomes apparent that the most conservative, yet still realistic, segregation distance is that distance which would prevent the tank cars from being involved in the same derailment. However, it is possible to stipulate conditions (e.g. relatively flat, adsorptive surfaces) where segregation of the rail tank cars would prevent and/or minimize mixing. One set of such conditions is given as follows:

Group	ASTM Reactivity Group																											
1	Non-oxidizing mineral acids	1																										
2	Oxidizing mineral acids	x	2																									
3	Organic acids		x	3																								
4	Alcohols and glycols	x	x		4																							
5	Aldehydes	x	x	x		5																						
7	Aliphatic and aromatic amines		x				7																					
10	Caustics	x	x	x		x		10																				
13	Esters	x	x					x	13																			
14	Ethers		x							14																		
16	Aromatic hydrocarbons	x	x					x			16																	
17	Halogenated organics	x	x				x	x				17																
18	Isocyanates	x	x		x			x					18															
19	Ketones	x	x					x						19														
20	Mercaptans and organic sulfides														20													
21	Elemental alkali metals		x													21												
24	Toxic metal compounds		x					x									24											
26	Nitriles	x	x				x	x										26										
27	Organic nitro compounds		x																27									
28	Unsaturated aliphatic hydrocarbons		x																	28								
29	Saturated aliphatic hydrocarbons																				29							
31	Phenols and cresols		x															x				31						
34	Epoxides		x																				34					
101	Combustibles and flammables		x																					101				
104	Strong oxidizing agents	x	x		x			x	x		x													x	104			
105	Strong reducing agents	x	x					x																		105		
106	Mixtures containing water		x																						x		106	
107	Water reactive substances		x					x																				107

"X" = Incompatible Groups

FIGURE 10. MATRIX OF INCOMPATIBLE CHEMICAL GROUPS BASED ON RISK

- Spills occur on level terrain comprised of soil
- Circular spill patterns
- Soil adsorbs about 12 kg liquid/m^2 (equivalent to about a 10 mm depth of liquid standing on an impermeable surface)
- 100 tons (75.7 m^3) of HAZMAT spilled per tank car with two tank cars spilled
- 50 percent of each chemical must mix to obtain significant consequences.

With these assumptions, the calculated segregation distance is about 40 meters between the cars after the spill occurred (i.e. after derailment). Because the tank cars may "stack-up" during a derailment, the spacing distance between the tank cars in the non-derailed consist may be considerably greater than 40 meters. For example, Figure 4 illustrates locations of rail cars following a derailment. If the position following derailment of rail car #24 TP shown in Figure 4 is taken as one point, then by using the 40-meter segregation distance it would be possible to have mixing of chemicals with rail car #54 TTD. Thus, for this example, the spacing distance in the non-derailed consist would be 30 rail cars. This, however, is a worst-case scenario. Assuming an average maximum of 13 cars derailed (Table 6, page 22) and stacked side-by-side, an in-train separation by 15 cars would provide the post-derailment distance of 40 meters to minimize commingling of incompatible chemicals.

3.5 Task 2 Conclusions/Recommendations

The compatibility of binary combinations of the top 101 hazardous commodities and fuming nitric acid was determined. Consequence calculations were performed to determine the area above lethal limits for toxic emissions, fireballs, unconfined vapor cloud explosions, pool fires, and condensed phase explosions. The chemical combinations were rank ordered based on severity of the consequences and relative risk. The chemicals were then placed into groups based on similar chemical structure or reactivity and matrices were developed which indicate the chemical groups which have the greatest consequences or risks when mixed together. If it is found necessary to reduce the risk of mixing of the combinations shown in Figure 9 during a derailment, separation of the tank cars in a train consist may be necessary. While separation distance of 30 railcars would minimize the mixing of incompatible commodities under a worst-case derailment scenario, a 15-car separation may be more practical and realistic.

4.0 TASK ITEM 3 -- OPERATIONAL CONSTRAINTS

Task Item 3 was the third of the six items which comprise Task Order No. 6. It consisted of two interrelated activities as follows:

3-1. Review the nature of current railroad operations and assess the processes to which railcars, especially hazardous materials cars, are subjected in normal transport activities. The processes are to include car pickup from source, transport to classification yard, yard operations, enroute activities, final classification, and delivery.

3-2. Examine the results of the review/assessment relative to the findings from Task Items 1 and 2, and determine the potential impact on current railroad operating procedures that the constraints on the in-train placement of hazardous materials cars may have.

These two activities were conducted in an essentially sequential manner. The former being carried out as a "new" effort within the overall Technical Task, and the latter as an integrated interaction between the former and the results of the previously completed Task Items 1 and 2. The work and findings associated with each activity are described below.

4.1 Review and Assessment of Current Railroad Operations

Those aspects of railroad operations which relate to the in-train placement of railcars were reviewed and assessed. Attention was given to the process of placement and the impact of placement requirements upon railroad operations. These processes were investigated via literature reviews [e.g., Ref. 24, Ref. 25], firsthand observations of railroad classification operations, and detailed discussions with Battelle's consultant.[1]

It was determined that there are three (3) major car placement

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1 Mr. John O. Riddle, a retired Superintendent of Operations for the Ohio Division of CSX (Chessie System). He has forty-four years of railroad experience in a variety of positions.

factors which are commonly considered when trains are initially made-up, or when cars are removed from and/or inserted into existing train consists. These are: (1) Operational Efficiency, (2) Federal Regulations, and (3) Derailment Dynamics.

1. **Operational Efficiency.** The desire here is to facilitate both the building (classification) of trains at terminal locations and the over the road operation of trains while they are enroute from their initial terminal (point of origin) to their final terminal (point of termination) where the cars in the inbound trains will be delivered to customers or reclassified into new trains. The basic goal is to minimize the number and/or complexity of switching movements within the terminals as well as those associated with over the road trips. Those relative to the latter are required when trains pick-up or set-off cars at locations (e.g. stations/yards, industrial spurs) intermediate to their initial and final terminals. It is standard railroad practice at terminals and yards to group together all cars bound for the same destination into a "block" of cars. Trains are built as sets of blocks corresponding to locations along their routes. These blocks are placed in "station order" within each train, with that associated with the first station to be encountered at the head end. Since all cars to be set out at a given location are then coupled together (as a block) within the trains, setting out can be confined to a single cut (block) of cars rather than requiring several separate switches to extract individual cars from locations throughout the train. Also, since the block of cars to be switched is normally immediately behind the locomotive, the total number of cars involved in the switching process is minimized. Arranging cars in blocks also facilitates their handling at classification yards; again, they can often be handled in groups rather than as individual units.

2. **DOT Regulations.** The requirement here is for conformance to the mandatory DOT regulations concerning the "handling of placarded cars". The applicable regulations are Sections §174.86 through §174.93 within 49 CFR Subpart D. These were previously discussed in Section 2.4 (Review of Current Regulations) of this report, and full copies are provided in Appendix D. As was noted, there are two primary classes of restrictions on in-train car placement: those relative to proximity to people on board, and those relative to adjacency to other cars based upon type and/or content of both cars. In making-up trains, specific care is taken to conform to the DOT regulations. As necessary, cars are suitably arranged within the blocks; in some instances it may be necessary to build a train with some cars outside their normal blocks, or with the

blocks not in station order. It may be necessary, such as in the case of a relatively short local train, to haul extra cars for the sole purpose of providing proper in-train locations for placarded cars. It should be noted that, at present, the DOT placement requirements are less restrictive for "short trains". Such "trains" can include cuts of cars being set-off and/or picked up by yard crews operating within yard limits, and some local trains. It appears that these requirements are not applicable to cars located on industrial sidings/spurs, or within industrial complexes, and, therefore, not on "railroad property". Also, with the increasing use of end-of-train devices, rather than cabooses, it is now possible to locate any hazardous materials car at the extreme rear of trains.

3. **Derailment Dynamics.** The goal here is to avoid building trains having inherent dynamic operating characteristics which could promote, or contribute to, derailments or pull-aparts. Such characteristics can result from unfavorable relative placements of loaded and empty (i.e. heavy and light) cars within a train. The potential for, and severity of derailments is, of course, also related to the physical characteristics of the route over which the train travels, and the train handling procedures employed by the engineer. The general rule relative to in-train car placement is to place the loaded cars at the front of the train and the empty cars behind them. However, some railroads, except for obvious and/or extreme situations, pay relatively little attention to this factor. Rather, they rely upon the engineers to provide proper train handling as necessary to prevent derailments or pull-aparts. Prior to departure, engineers are provided with "train profiles" which cite the positions of loads and empties, and indicate the weight of the loads. The location and number of light cars in a train can also influence the manner in which helper service is employed; helper engines can either push from the rear or be double-headed at the front. The latter might be used to avoid unfavorable dynamics if there were a large number of light cars in the rear portion of the train requiring help.

Of these three car placement factors, the railroads give initial consideration and emphasis to the first, Operational Efficiency, the goal being to build trains consisting of blocks of cars in station order. However, deviations to this basic goal are made as necessary to accommodate the DOT regulations pertaining to placarded cars, and, to a much lesser extent, to avoid unfavorable derailment dynamics. It should be noted that there are work agreements which, except for those situations resulting from conformance to DOT regulations, require the railroads to pay train crews a premium if their train make-up is such that "excessive" switching movements are required during their trip.

The processes which a railcar undergoes from the time it is picked up at its source (i.e. the location at which it was loaded) until it is delivered at its ultimate destination were reviewed. Three major interrelated activities/processes were identified. These are: (1) local pick-up and set-out of cars, (2) car classification, and (3) line haul. Individual cars are subjected to all of these, one or more times each, during the pick-up to delivery cycle. The basic cycle starts with the delivery of an empty car to a shipper. At a later time, after the car is loaded, it is picked up and taken to a relatively nearby classification yard. From there it is either delivered to its destination by a yard crew, a local train, or, more probably, hauled to a major classification yard by a through train. It may then be delivered by a yard crew, a local train or hauled to yet another classification yard. The process is repeated until the loaded car reaches its ultimate destination. This may involve one or more individual railroads depending upon the destination, available routes, and the shipper's options and choices.

Normal railroad operations procedures are modified to accomodate handling of hazmat cars. For example, loaded cars are picked up from sidings and spurs by local trains or yard crews. If hazmat cars are involved, extra cars may be carried by the local train to provide the necessary separation from locomotive or caboose required by DOT regulations.

Operations in the classification of cars (i.e., the sorting and grouping of cars according to their destination) is modified by the presence of hazmat cars. There are restrictions on the switching of placarded cars. These are given in Sections §174.83 (Switching of cars containing hazardous materials) and §174.84 (Switching of flatcars carrying placarded trailers, freight containers, portable tanks or IM portable tanks) within Subpart D of 49 CFR Ch. I. These restrictions prohibit the cut-off of specific placarded cars while they are in motion, as well as the striking of these cars by any car moving under its own momentum. Such restrictions apply at all times and, therefore, impact switching operations on the road and in classification yards. Both flat yard and gravity (hump) yard operations are affected. Such procedures as shoving cars to rest, rather than "kicking" or humping them, must be employed. If necessary, placarded cars are held out for later insertion into the classified blocks in accordance with these DOT regulations.

Any train may be required to stop in order to set off a bad order car (one with an overheated journal or other mechanical defect) detected enroute. This is done at the first available siding or spur in the same manner as cars normally delivered to such locations. The removal of these cars could result in the unfavorable placement of placarded cars. In such cases, it is also necessary to reposition these cars within the train.

4.2 Determination of Impact of Additional Placement Constraints

The potential impact of additional in-train car placement constraints on current railroad operations was investigated. The operations considered here are those associated with the source to destination transport of loaded railcars, especially hazardous materials cars, described above in Section 4.1. The constraints are of two separate types: (1) those related to placing hazmat cars in that section(s) of trains where derailments are least likely to occur, and (2) those related to providing in-train separation of hazmat loads which have been determined to be "incompatible" so as to preclude commingling in a derailment scenario. These constraints were previously discussed in Sections 2.0 (Task Item 1--Review of Accident Trends and Regulation) and 3.0 (Task Item 2--Hazardous Materials Compatibility), respectively. In conducting this work, it was assumed that any placement requirements which might arise from such constraints would be in addition to those already required under current Federal regulations.

Battelle's analysis of accident/incident data for calendar years 1982-1985 showed that, when derailments occur, the distribution of derailed cars varies considerably with in-train placement. Cars located in the rear third of the train or, better yet, the rear quarter are much less likely to derail than cars placed elsewhere (see Table 2, page 8, for the percentage of cars derailed by in-train location). The implication is, therefore, that hazardous materials cars should be placed in the rear sections of trains whenever possible. However, if a train has a caboose, existing DOT regulations governing proximity to occupied cars precludes the placement of certain placarded cars in the next one to five positions.[2] The need for suitable in-train positions for hazardous materials cars will, of course, depend upon the number of such cars to be hauled in any given train.

According to Battelle's findings, if it is not possible to place a hazmat car in the rear quarter (or third) of a train, the next most favorable location is the front quarter (or third). Therefore, placing quantities of placarded cars so as to minimize their potential for derailment is not merely a matter of positioning them as far to the rear as previous placements permit (that is, if the rear quarter is unavailable, place them in the third quarter until it is filled, and so on). Rather, if the rear quarter cannot accommodate additional hazmat cars, they should be placed in the first quarter, then the third quarter, and finally, the second quarter.[3] However, the analysis showed there is relatively little advantage in placing cars in the third quarter rather than the second.

Present DOT regulations contain language which restrict the placement of specific placarded cars relative to specific other placarded cars. These restrictions are based upon both "type of car" and "placard applied on car" conditions. However, their number is fairly limited and, in all instances, preclude only placements in which the subject cars would be immediately next to (i.e. coupled to) each other. There are no requirements calling for additional separation of two placarded cars regardless of their contents. An activity of Task Item 2 was to determine minimum in-train segregation distances between cars carrying "incompatible" hazmat so as to preclude commingling of these materials

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2 Identical restrictions exist relative to proximity of placarded cars to locomotives. See Appendix D for details of the applicable regulations.

3 It will be noted that, in this regard, Battelle's findings differ from those presented in the 1979 DOT/TSC report [Ref. 1]. That report indicates a strategy of placing placarded cars as far to the rear of a train as possibly could be employed. See Table 1 for the applicable findings of the DOT/TSC analysis.

should the associated cars derail. Such distances (i.e. number of intervening cars) were considered for those pairs of the 102 hazardous commodities investigated which were determined to be sufficiently incompatible to warrant such.

It was ascertained that, for the 102 commodities, there are in excess of 1,000 incompatible pairs (out of 5,151 possibly binary combinations). The incompatible pairs were displayed on a chemical group basis in Figure 9, page 75. The group assignments for the individual commodities was given in Figure 5, page 49. The analyses related to the determination of in-train separation distances was done on a general basis, rather than on a per-pair basis. The suggested spacing for incompatible hazmat commodity pairs is 30 cars (see discussion in Section 3.4).

Neither of the two placement constraints discussed above (i.e. place hazmat cars in selected locations, and provide suitable separation between cars carrying specific hazmat) are in conflict with existing DOT in-train car placement regulations. Indeed, the second can be viewed as an extension of existing requirements. However, there is potential for conflict between the two constraints themselves. On one hand, it is desirable to locate all hazmat cars in the rear of trains; on the other, separations of many cars may be required between certain of these, thereby limiting the number of available car positions in the rear. Of course, it may be possible to provide the desired separation by inserting other hazmat cars which are not themselves subject to spacing requirements. However, the relatively large number of incompatible pairs, together with the considerable in-train separation distances associated with them, may well result in an irresolvable conflict. Indeed hauling a single incompatible pair of cars would require a train length of at least 96 positions in order for them to both be in the rear third of the train and 30 cars apart. The extent to which such conflicts might arise will depend upon the number and nature of the hazmat cars to be hauled by any given train. Some railroads routinely haul considerable hazmat, both in volume and variety, and even operate some fairly "solid trains" of hazmat cars (these tend to contain a limited number of commodities; possibly, only one). Others may carry very little, and the presence of hazmat would constitute an exception to normal operations.

Obviously, the more requirements imposed upon the railroads relative to in-train car placement, the greater the potential for impact upon their present operational processes. An overview of potential impacts, as presently envisioned, is presented in Table 12. No measures of absolute or relative significance have been assigned to the items listed therein; rather, the intent was to identify their nature and extent. While there is some degree of overlap between some items, it was considered desirable to include both general and specific impacts. It should be noted that the determination of impact, as examined here, assumed the imposition of requirements relative to both placement constraints: location in train, and separation. However, it is recognized that either constraint could be used alone; in such case, the extent of the impacts would be reduced. It is apparent that there are a number of areas/processes that would be impacted and, depending upon the amount and type of hazmat actually involved, the impact potential could be very significant. The areas include activities, procedures, performance, schedules, and costs. Foremost, any requirements directed toward congregating any and all hazmat cars in specific portions of trains would be in direct conflict with the railroads' practice of grouping cars in destination-specific blocks, and placing these blocks in station order within trains. Further, the basic process of car classification would be complicated by the need both to place hazmat cars in the rear of trains, and to ensure that the necessary separation distances are provided. While the latter is presently observed in accordance with current DOT regulations, future separation requirements may be greatly expanded relative to both number of cars involved and the variety of the associated separation distances. This could necessitate considerable additional sorting, switching and classification activity in order to make up trains which conform to these requirements.

The placement constraints being considered here would also complicate the activities associated with the pick-up and set-off of cars by local or through trains. The loss of the block structure could greatly increase the number of individual switching movements required during set-offs. Likewise, the pick-up of hazardous materials cars could require

TABLE 12. POTENTIAL IMPACTS ON RAILROAD OPERATIONS DUE TO ADDITIONAL IN-TRAIN CAR PLACEMENT REQUIREMENTS

- Need for training programs and materials to promote awareness and understanding of new requirements among railroad personnel.

- Possible need for revised and/or supplementary placards, or other means, to readily convey the need for, and amount of, separation required for specific pairs of hazmat cars. Likewise, revise content of consist lists, waybills, etc.

- Possible need to carry more "extra" cars, especially on short trains, for the sole purpose of providing suitable locations for and/or separation of hazmat cars.

- Need for additional switching movements in association with the set-out of cars at sidings/spurs due to increased need to extract individual cars from trains rather than setting-out single cuts of cars. Also, the loss of strict station order may result in the need to involve more cars in each movement. Further, once set-out is made, it may be necessary to shift some of the existing cars in order to reestablish/maintain required placements and separations.

- Need for additional switching movements in association with the pick-up of cars at sidings/spurs due to the need to place, and suitably separate, picked-up hazmat cars in the rear of the train rather than accumulating them mostly at random in the front. Possible conflicts with cars already in the train could necessitate additional switching movements. Also, it may be necessary for most of the train to be backed-in to pick-up a hazmat car, rather than merely using the engine and, perhaps, a few cars only.

- Possible conflict with car placement strategies sometimes used to preclude unfavorable derailment dynamics (i.e. place empty cars in the rear of trains). Also, deliberately placing hazmat cars in the rear could sometimes effect the use of helper service, especially since the declining use of cabooses allows such cars to be placed in the last five positions. If helper engines were scheduled to push, they would be within the range of nearness to engine prohibited by current DOT regulations. However, help could be provided by double heading the engines rather than pushing.

- Need for additional time, effort, and equipment to perform the additional switching movements which may be required throughout all aspects of railroad car processing operations. Associated with this could be additional labor needs, equipment wear, engine fuel usage, and perhaps a need for revised assignments for personnel and equipment.

TABLE 12. (Continued)

- Considerable conflict with the railroads' desire to build and operate trains consisting of blocks of cars in station order. Such may not be possible in trains containing even small numbers of hazmat cars.

- Difficulties in building trains due to additional, and possibly complex, needs to insert placarded cars in specific in-train locations and with specific minimum separations. It may be necessary to perform considerable "extra" car sorting/reclassification. And, much of this might be required immediately prior to train departure since total train lengths and consists are generally not known well in advance. Both flat and gravity type yards could require the use of separate classification tracks to build the hazmat car portions of trains. It might even be necessary to construct additional classification tracks and/or receiving/holding tracks to support such additional classification activities.

- Need for additional time/effort to build trains and/or set-off and pick-up cars could occasionally delay or permanently extend existing schedules. This could result in the need to quote longer delivery times to shippers. Longer trip times could frequently result and, in some instances, it may be necessary to pay train crews for more work hours, including some at overtime rates. If over the road trips times became "excessive", the Federal Twelve-Hour Work Rule could be imposed. In such cases, it would be necessary to transport a relief crew to the stopped train, and deadhead the regular crew to the terminal. Both traffic delays and extra labor costs would result.

- Possible need to provide extra compensation to train crews if their trains are so built that "excessive" switching movements are required in the course of their trip. While, at present, such "work agreements" do not appear to be applicable if the additional movements are the consequence of building trains in accordance with DOT regulations for placarded cars, they could become so if the number of such movements increased and was deemed unreasonable by the crews. This might then become an issue in future labor negotiations.

- Possible increased severity of rear-end collisions. The increased presence of hazmat cars in the rear of trains (including the last position in trains using end-of-train devices rather than cabooses) would constitute an increased hazard to crews of following trains. While this situation presently exists, it could be worsened by the deliberate concentration of hazmat cars in the rear.

additional movements to achieve both rear of train placement and proper separation. As discussed in Section 4.1.1, "car classification" and "local pick-up and set-out cars" are two of the three major activities associated with the source-to-destination processing of railcars. The third, "line haul", may also be impacted, either directly or indirectly, via the other two.

In general, implementing and employing the necessary operational changes can be expected to have a negative impact upon operating costs. In return, reductions in the number and severity of hazmat car derailments can be expected. Should a train configured in accordance with the above discussed placement considerations derail, the likelihood of hazmat cars derailing would be reduced. And, should such cars derail and release, the likelihood of commingling of incompatible hazardous commodities would be reduced.

5.0 TASK ITEM 4 -- COST/BENEFIT ANALYSIS

Task Item 4 was the fourth of the six items which comprise Task Order No. 6. It consisted of two interrelated activities as follows:

4-1. Identify the items to be considered in a cost/benefit analysis, based on the findings of Task Items 1 through 3. Included will be the cost of "extra" activities necessary to place hazmat cars at locations within trains with reduced probability of derailment, and at segregation distances which reduce the probability of commingling of incompatible materials. Benefits will include the reduction in number and severity of hazmat spills.

4-2. Refer to derailments identified in Task Item 1 that may have been avoided or, at least, reduced in severity by better placement of hazmat cars. For each, determine how the train was made up prior to the accident, and identify actions that would have been required to avoid "unsafe" hazmat car placement. And, estimate the cost of these actions in terms of additional labor, lost time, etc.

The statement of work covering this task item[1] contained the following:

> "Before any new regulations or changes to existing regulations can be implemented, a cost/benefit study is needed. In this effort a preliminary cost/benefit study will be required to identify issues for consideration in a more detailed study (to be conducted by the FRA's Office of Safety). Any accidents identified should be included so that the cost basis of preventing such a situation from occurring can be determined."

Accordingly, Battelle's cost/benefit work in association with Task Item 4 -- Cost/Benefit Analysis is largely of a qualitative nature. As appropriate to do so, quantitative materials are included as well.

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1 Section 2.0 (Technical Discussion) of the Statement of Work for Task Order No. 6 - Hazardous Materials Car Placement in a Train Consist, DOT/FRA, September 15, 1987.

5.1 Identification of Items to be Considered in a Cost/Benefit Analysis

The costs of interest here are those affecting the selective in-train placement and separation of hazmat cars. Included are not only the value of the labor, materials, and equipment necessary to do so, but any adverse impacts on railroad operations which may occur in consequence. Likewise, benefits include both reductions of the number and severity of derailments involving hazmat, and such other cost savings or improvements that might also result. The following material first provides an overview of the potential impact of new hazmat car placement requirements upon derailments, and then discusses benefits and costs as separate items.

There is no basis for expecting that the implementation of new in-train placement requirements for hazmat cars will result in a decrease in the total number of derailments occurring in the U.S., or in the total number of cars derailed. What can be expected is a decrease in the number of hazmat cars which derail and, therefore, in the number which release hazardous materials. Derailments would still occur, but they would involve increased numbers of non-hazmat cars.[2] Hazmat car derailments would not be eliminated since they can involve any position within a train; there are no "derailment exempt" positions. The selective placement of hazmat cars can merely reduce the probability of their derailing, not guarantee immunity against such. Indeed, many derailments are initiated by car failures (e.g. broken wheel) rather than "external" causes such as rail rollover or poor train handling. Thus, relocating hazmat cars which then fail enroute will merely relocate the position within the train where derailment initiates and still involve these cars. Also, it can be expected that there would be a decrease in

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[2] It can be expected that, in general, most derailments will involve the same car positions regardless of the type of cars and/or lading. Therefore, locating hazmat cars in the "safest" positions will provide them with protection, but leave other cars more vulnerable to derailment.

the probability of commingling of incompatible hazardous commodities.[3] Therefore, a decrease in the severity of the consequences of derailments in general can be expected, as well as a decrease in the number of severity of "catastrophic" accidents involving hazmat release such as the Miamisburg, Ohio, accident on July 8, 1986.

NTSB's Railroad Accident Reports commonly contain a section entitled "Damage" wherein (usually brief) descriptions of the nature and extent of the damage associated with each accident are discussed. Also included are estimates of the cost of the accident damages which are separated into major cost item categories. A review of several of these reports (not all of which involved hazmat) showed that the most commonly used categories are "train equipment", "train lading", and "track". Others utilized were: "bridge", "salvage and wrecking", "nonrailroad", "signals and appurtenances", "lading transfer", "cleanup", "emergency response", "civilian response", "environmental restoration/cleanup", "wreck clearing", "overtime", and "miscellaneous". In the single noted usage of the last category, it was further explained to include evacuation costs, personal injury and property damage payments, as well as expenses related to air, soil, and water treatment, and the excavation and shipment of contaminated soil. It appears that the categories employed, and the contents thereof, are selected by the railroad which had the accident and, therefore, provides the cost estimate.

As can be seen, there is a large range of possible cost items which can be directly associated with a railroad accident. In addition, there may be other indirect costs, such as the loss of the use of the

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3 The work conducted under Task Item 2 indicated there were various groups of incompatible hazmat commodities which should be separated to preclude commingling should they release during derailment. However, as previously noted, the review of NTSB Accident Reports conducted under Task Item 1 (see Table 9) did not uncover any accidents where commingling was specifically cited as a contributing factor to the severity of accident consequences. While the potential for the commingling of incompatible hazmat appeared to exist in several instances, for whatever reasons it did not occur. Nevertheless, the potential for severe consequences due to commingling exists.

rail line until the accident wreckage is cleared and all damage repaired. Obviously, all accidents will result in some cost whether or not hazmat cars were actively involved or even present. For example, "initial" damage to cars, track, signals, etc., can be expected to be "similar" regardless of the contents of the car(s) which actually derail. However, "subsequent" effects and related damage can become considerably worse when hazmat is involved. Fires and explosions associated with hazardous materials can cause additional extensive damage to both railroad property (the train itself as well as track, structures, and equipment) and adjacent properties and populations. The discussion on risks in FRA's Docket HM-175 [Ref. 26] pointed out that the particular effects of a release of hazmat depend upon the properties of the material released, the quantity released, and the overall accident scenario. And, the major sources of concern have been: (1) boiling liquid expanding vapor explosions--BLEVEs, (2) tank rocketing, and (3) toxic and asphyxiating clouds of gas. This source also notes that the extent of economic losses and injuries depends on the size of the population at risk. In turn, this depends on the range over which the hazmat lading can spread or a tank car can rocket.

The beneficial effects of employing in-train placement and separation requirements for hazmat cars appear to be entirely related to reductions in hazmat releases and associated detrimental consequences. No operational improvements or other non-derailment related benefits were uncovered. Therefore, the identification of benefits can be primarily based upon the removal of the differential portions of the losses and costs associated with past derailments involving hazmat which are directly attributable to the presence and/or involvement of the hazmat. An overview of the expected benefits associated with such reductions is presented in Table 13. The manner in which the items contained therein are couched is in keeping with the premise that benefits will arise directly from the reduction in hazmat involvement in a derailment scenario.

It is necessary to ascribe monetary values to all benefit items so that, ultimately, the total value of the "overall benefit" can be

TABLE 13. BENEFITS ASSOCIATED WITH THE REDUCTION OF THE INVOLVEMENT OF HAZMAT CARS IN DERAILMENT SCENARIOS

- Reduction in Post Derailment Effects. Adverse effects which can occur subsequent to (immediately following or later on) the initial accident/derailment will be reduced. While it can be expected that, in general, the initial effects (e.g. car and track damage resulting from the physical consequences of derailing) will be essentially unchanged, subsequent effects can be substantially worse when hazmat is involved. The elimination/reduction of direct hazmat involvement from the post derailment scene can be expected to eliminate/reduce major fires, explosions, and tank car rocketing, as well as the release of toxic or asphyxiating fumes/clouds. Further, there will be a reduction in the size of the area of involvement (i.e. that which is actually or potentially subject to adverse conditions or effects) as a direct consequence of lading involvement in the post derailment scenario. Hazmat related fumes and clouds are of particular concern since they can affect large areas in the vicinity of the derailment, and their position and extent are often predictable.

- Reduction in Injuries and Deaths. The less "severe" the post derailment effects, the less the risk to all persons "involved" in the overall derailment scenario. This includes the train crew as well as the population in the vicinity of derailment; both relative to the nature and severity of the effects, and from the size of the area of involvement. Further, the less severe/extensive the effects, the fewer the number of "emergency forces" personnel which will be required to combat these effects (to both eliminate the associated hazards and restore train service on the line), and the lower the levels of the risks to which they will be exposed. The risks to people include both immediate and future impacts on health, and both direct (e.g. burns) and indirect (e.g. future toxic material ingestion from a contaminated water table) harm as consequences of hazmat release. Reducing the numbers of persons killed or injured will be most beneficial from not only a monetary standpoint, but from a humanitarian one as well.

- Reduction in Loss of Railroad Equipment. The less "severe" the post derailment effects, the less the potential for additional damage (due to fire, explosions, etc.) to the train consist, especially to those cars which were initially derailed and/or damaged or which are in close proximity to them. Such effects can both completely destroy the car(s) in which they initiated, and readily involve adjacent cars (e.g. fire impinges upon and ignites them) causing their damage or destruction. Additionally, the lading contained in the adjacent cars may then further compound the incident. It may be of such nature as to support, or even worsen, the existing situation. Rocketing tank cars are commonly the consequence of non-releasing tank cars being heated by adjacent flame sources. With reduced post derailment effects, there will be fewer adjacent cars involved, and to a reduced level of involvement. This

TABLE 13. (Continued)

consideration extends to all other railroad equipment in the vicinity of the derailment which can include both major and minor items such as track, switches,roadbed, bridges, trestles, pole lines, signal masts, cases and circuits, crossing gates, and structures. Further, the need to decontaminate railcars and/or other equipment will be reduced or eliminated.

- Reduction in Loss of Lading. Along with the reduction in the loss of, or damage to, rail cars discussed in the above item, would be a corresponding reduction in the loss of, or damage to, lading contained in the affected cars. Of particular concern here is the loss/damage which occurs subsequent to the actual derailment, and is therefore related to the post derailment effects (e.g. fire and explosion). Other lading related considerations are thermal damage incurred by lading not directly involved in the initial or subsequent derailment effects, or lading contamination resulting from released hazmat. While not necessarily confined to hazmat, there would be reduced loss of lading due to liquid spills and vapor boil-off. In general, there would be less lading damaged and more which could be salvaged, and with less difficulty.

- Reduction in Loss of Rail Service. The less "severe" the post derailment effects, the less the potential for loss of rail service capacity. It can be expected that with reduced damage and/or contamination, service on the line can be reinitiated sooner. This includes both the opening of the damaged section to traffic and the lifting of any slow orders that may initially be imposed. Further, the reduction in train damage as previously discussed would make more railcars and locomotives available sooner for use in revenue producing service.

- Reduction in Loss to Adjacent Properties. The less "severe" the post derailment effects, the less the potential for additional damage (beyond that caused by the physical nature of the initial accident) to all manner of adjacent non-railroad properties such as structures, facilities, equipment, lawns, gardens and cultivated lands, and livestock. The injury and death of people was addressed separately in a previous item, and natural areas and their contents are addressed in the next item which is concerned with the environment. Property loss can range from minor damage to complete destruction and can result from direct exposure to burning cars and lading, from contact with released lading (depending upon the nature and amount of the commodities released), to, especially, the effects of explosions. The latter includes both blast effects (force and thermal) and impacts by objects propelled by explosive forces. It is not uncommon for entire tank cars to be propelled/rocketed considerable distances when their contents explode.

TABLE 13. (Continued)

- Reduction in Impact Upon Environment. The same effects which can cause losses to adjacent properties can also adversely impact the environment. Therefore, reductions in the severity and/or area of impact of post derailment effects will result in reduction in the overall environmental impact. Such impact can include not only direct damage to nearby flora and fauna due to fires and explosions, but contamination of adjacent soil, water, and air. Soil contamination can present a local (i.e., contact) hazard to all living organisms, and, possibly, affect the local water table as well. Affected waterways can range from drainage ditches associated with the railroad right-of-way, to small streams, to rivers and lakes. Their contamination can present a direct hazard to aquatic life, and render them unfit for recreational activities or use as water supplies for crop irrigation, human consumption, or industry. There is the potential for air pollution not only from the release of hazmat (vapors or particulates), but from the products of combustion associated with fires and explosions. Damage to the environment can be extensive and long-term and not readily corrected, and can result from not only the effects directly attributable to the derailment, but due to the activities associated with combating the associated hazards and clearing the wreckage. The latter can include both physical damage from heavy equipment, from constructing impoundments to contain spills, and from chemical substances used to mitigate the effects of released hazmat.

- Reduction in Disruption to Populated Areas. In addition to reductions in injuries, deaths, and property damage, as previously discussed, less "severe" post derailment effects would also result in reduced disruption to the everyday private and commercial activities of nearby populated areas. A major benefit would be less frequent need for evacuations and/or for less extensive areas and/or for shorter periods. Besides the inconvenience and costs associated with transporting, housing, and feeding displaced populations, there are direct costs related to closing businesses (e.g. loss of production and sales, loss of wages). Additional, less quantifiable, costs are associated with the closing of both public and private facilities such as schools, nursing homes, and hospitals. Even in cases where evacuation is not required, severe disruption can occur. There could be damage to nearby electrical power transmission lines or communications systems which could have far-reaching effects. Likewise, it may be necessary to close nearby highways and navigable waterways; this could result in indirect losses to users who would be required to find less effective alternatives.

- Reduction in Emergency Response Efforts. The less "severe" the post derailment effects, the less effort which will be required to bring fires, explosions, and releases under control. The potential for reduction in such efforts can extend throughout the entire recovery process; from the initial assessment of the situation, to the organization of emergency response

TABLE 13. (Continued)

forces, to combating and controlling all adverse effects so as to render the derailment site "safe". The primary thrust here is to remove derailment-related threats to the area in general, and provide an environment in which wreck clearing and rail service reinitiation activities can be readily carried out. The reduction/elimination of hazmat and hazmat-related effects from the derailment scenario will reduce/eliminate the need for, often extensive, emergency response efforts. These include ascertaining response needs based upon what lading is involved and how it should be handled (this is not always readily determined), assembling special forces, equipment, and materials at the derailment site, and conducting such activities as may be required to control, contain, and/or recover hazmat which has been released or is considered to be vulnerable to anticipated wreck clearing activities. In general, it can be expected that the less severe the post derailment effects, the safer, faster, easier, and less expensive the emergency response efforts.

- **Reduction in Wreck Clearing/Service Restoration Efforts**. With a reduction in post derailment effects will be a corresponding reduction in the time and effort necessary to clear/repair associated wreckage and restore service on the line. That is, the effects of fires and explosions (which compound and expand on the initial derailment-related damage) on railroad property will be reduced/eliminated. This includes a reduction in the number of railcars damaged and the extent of their damage. Likewise, damage to all other railroad equipment and structures in the vicinity of the derailment can be expected to be reduced. In turn, there will be less need to transfer lading, transport (rather than rerail) cars, replace heat or blast damaged equipment and materials, and complete such other activities as may be necessary to clear away the wreckage and restore the line to such condition that service can be restored. This includes both "reopening" the line initially under restricted conditions (e.g. slow orders), and its eventual restoration to, at least, the service level which existed prior to the derailment. The reduction of the wreckage/damage to be handled will reduce the manpower, equipment, and materials required to restore service; savings in time and costs will result.

- **Reduction in Environmental Restoration Efforts**. Along with the potential for reductions in the impact of post derailment effects upon the environment, will be the potential for corresponding reductions in the efforts and costs associated with restoration. Obviously, if less "damage" occurs, less corrective measures will be required. A major cost item can result in cases where it is necessary to excavate contaminated soil and transport it to a "safe" site for treatment and disposal. It can also be necessary to treat bodies of water which may incur hazmat contamination. Costs will also be associated with derailment site testing to determine contamination levels and, therefore, decontamination needs, and with monitoring of residual

TABLE 13. (Continued)

effects over relatively long periods. The extent to which environment related costs are incurred will depend upon the nature and extent of the damage, and the applicable Federal and State Environmental Protection Agency regulations and policies. It may be possible that the situation could arise where the responsible railroad would not only be required to pay restoration costs, but would be fined as well.

- Reduction in Involvement by All Parties. The less "severe" the post derailment effects, the less the need for direct involvement by various persons, both from the railroad and from external organizations. It can be expected that when hazmat is involved, there will be a potential for more extensive involvement by more persons and organizations. Not only is it necessary to combat effects that may be worse than otherwise, but the involvement of hazmat in the accident scenario will both require special consideration and attract attention. Among the non-railroad organizations which become involved are: local fire, police, and emergency units, state police, state fire marshal, state Environmental Protection Agency, hazmat car owner/commodity shipper, National Guard units, U.S. Coast Guard (if navigable waterway is involved), National Transportation Safety Board, and Federal Railroad Administration. All this involvement can result in a considerable expense, both to these organizations and to the railroad which must inform, involve, and coordinate with them; and, perhaps, pay for their participation.

- Reduction in Adverse Publicity. The presence of hazmat in the consist of a derailed train, especially if a release occurs, can attract "attention" from a wide range of individuals and organizations beyond those directly concerned with combating the derailment effects and clearing the wreckage. Among these are political bodies, regulatory agencies, news media, community action groups, and environmentalists. All of these must be properly informed and dealt with by railroad representatives to the extent necessary to meet legal and civic obligations. The associated activities can include inspections, interviews, public meetings and hearings; these can take place on site or elsewhere and can occur over a considerable period of time subsequent to the derailment. And, can result in a considerable expense to the railroad. A reduction in post derailment effects, especially those relating to hazmat, should also result in a reduction in actual and perceived risk to persons and property. In consequence, there will be a reduction in adverse publicity and the costs associated with the activities related thereto.

compared with the total value of the "overall cost" to determine whether or not the selective in-train placement and separation of hazmat cars is a cost effective endeavor. In determining the monetary value of benefits, it must first be recognized that all benefits under consideration here arise directly from the reduction or elimination of derailment related consequences and activities. Therefore, it is the dollar value of the associated losses and costs which must serve as the basis for costing benefits. However, it must also be recognized that, as previously indicated, it is only that portion of these losses/costs attributable to the presence and/or involvement of hazmat which should be utilized here. That is, certain damages, effects, costs, and/or losses associated with derailments are not attributable to hazmat and would have occurred even in the total absence of hazmat; the value of these should, therefore, be excluded. This requires that only selected costs/losses, or portions thereof, be utilized when determining potential benefits and their value.

Inspection of Table 13 shows that most of the potential benefits are of a highly tangible nature, but a few are not. For example, damage to equipment and lading can be readily quantified and the associated dollar loss determined. However, disruptions to the environment and adverse publicity are not easily quantified. Rather, only specific, directly identifiable portions of such items can be costed. Therefore, from a practical standpoint only quantifiable benefits, with definitive dollar values, can be utilized. Accordingly, a check list of quantifiable benefit items has been generated; it is based upon the contents of Table 13, the damage cost items utilized in NTSB Railroad Accident Reports, and the above cited considerations.[2] This list is as follows:

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2 Note that the Government does not use court settlements as the basis for cost/benefit analyses. Sometimes the insurance claim settlements are used. Currently the value for a life is $1 million. This applies to Items 1, 3, 4 and 5 below.

1. **Injuries and Deaths.** Costs related to the settlement of claims and/or awards in connection with the injury or death of any and all persons as a consequence of the derailment.

2. **Railroad Equipment.** Losses and/or costs related to the damage/ destruction of railroad equipment, facilities, and structures and, when so performed, the repair and or replacement of these materials.

3. **Lading.** Costs related to the settlement of claims by shippers and/or receivers in connection with lading (and cars, where company owned) which was damaged or destroyed as a consequence of the derailment.

4. **Non-Railroad Property.** Costs related to the settlement of claims in connection with the damage/destruction of non-railroad property of any and all type as a consequence of a derailment.

5. **Population Disruption.** Costs related to the settlement of claims by individuals, groups, municipalities, etc., for losses and/or costs associated with the disruption of their everyday activities. This includes the costs associated with evacuations.

6. **Emergency Response.** Costs related to the use of both railroad and non-railroad personnel, equipment, and materials to combat and eliminate hazardous conditions which result as a consequence of the derailment.

7. **Wreckage Clearing.** Costs associated with the use of manpower and equipment to clear the wreckage resulting from the derailment and related effects, and to restore service on the line. This work will be carried out by the railroads themselves with their own personnel or contractors. Replacement equipment costs are included in Item 2 above.

8. **Environmental Restoration.** Costs associated with activities directed toward the mitigation and/or correction of damage suffered by the environment as a consequence of the derailment. This can include the cost of decontamination, restoration, and other applicable activities.

9. **Miscellaneous.** Losses and/or costs not included in the above eight items which can be specifically identified relative to the derailment. These may vary from one derailment to another depending upon both their applicability and the railroad's ability to identify them.

Not surprisingly, the items in this listing are similar to the previously cited damage cost items used in NTSB Railroad Accident Reports. And, as in the case of those reports, the determination of the dollar value of the losses and costs can probably be best done by the railroads themselves since they should have access to the necessary data. Some of these will be well defined (e.g. claims, charges, fines paid to external parties), while others will require a judgmental determination (e.g. labor and materials, value of damaged or destroyed equipment). Further, some costs will be incurred by choice or necessity, others will result from court actions and awards. All applicable losses and costs, whether or not covered by the railroad or its insurance carrier, should be included in the determination of dollar value of benefits.

As in the case of benefits, quantifiable cost items must be identified so that the "costs" associated with employing in-train placement and separation requirements for hazmat cars (which foster the previously described benefits) can be determined. The impact items previously presented in Table 12, page 92 (Potential Impacts on Railroad Operations Due to Additional In-Train Car Placement Requirements) can serve as a direct basis for deriving the cost items. It is necessary to consider both the cost of the specific activities necessary to conform to additional hazmat car placement/separation requirements, and any negative effects[5] which result from having performed them. And, from these, identify labor and materials expenditures as well as operational performance losses for which dollar values can be ascribed. Unlike the "losses and costs" associated with benefits, which required separating out only those portions which related to the involvement of hazmat in the derailment scenario, these costs can be directly, and, with few exceptions, completely attributed to the hazmat car placement/separation requirements which necessitated them. Again, from a practical standpoint, only quantifiable items and costs, with definitive dollar values, should be utilized.

Examination of Table 12 reveals that some of the impact items

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5 Positive effects were previously considered under "benefits".

listed therein are in the nature of "one-time" activities/costs associated with the development and initiation of procedures and provisions to conform to new hazmat car position/separation requirements. However, most are of an ongoing and continuous nature with a variety of associated activities and costs. Some are of an obvious and direct nature (e.g. classification activities associated with the make-up of trains), while others are subtle and indirect (e.g. delays in schedules and delivery times). Obviously, the former are more readily quantifiable than the latter and can be better related to specific trains and trips if so desired.

The following is a check list of cost items. These have been separated into four major categories in order to better distinguish between those costs of a general nature and those associated with the operation of individual trains:

1. **Organization and Initiation.** Costs related to planning and providing the methods and means to conduct such activities as may be required to conform to in-train placement and separation requirements for hazmat cars. Includes preparing both work forces and facilities, along with developing effective and efficient procedures and processes for affecting the necessary placement/ separation when and where required. Specific cost items which could be included here are:

    a. Development of training programs and materials for instructing appropriate personnel, as well as carrying out the necessary instruction and otherwise disseminating all applicable information and instructions.

    b. Development of revisions to formats for consist lists, waybills, classification cut lists, and other documentation related to car lading and/or train make-up so as to provide railroad personnel with direction regarding the placement/ separation needs of individual hazmat cars.

    c. Development and utilization of revised placard and/or other car-mounted devices which readily convey information relative to the car's placement/separation.

    d. Development and implementation of revised classification procedures for use in yards and terminals so as to accommodate efficiently the additional handling needed to achieve the required placement/separation of hazmat cars.

e. Design and construction of revisions to existing yards and terminals, if such are warranted, to facilitate the handling/classification of hazmat cars when making up trains. Could also entail the need for more yard engines.

f. Development of revised schedules, restructured service routes, and other materials which define and direct freight service operations so as to accommodate any additional activities and time requirements associated to classifying and operating trains in conformance with the hazmat car placement/separation requirements.

2. **Overall Operations and Performance.** Costs and losses related to the general operation of railroads as reflected by increased operating needs/activities and/or diminished performance capabilities as a consequence of conforming to in-train placement and separation requirements for hazmat cars. Includes impacts upon personnel and equipment needs, as well as facility utilization, and upon overall operational efficiency and performance. Includes both items directly involving the handling of hazmat cars and the consequences of doing so as they affect other aspects of operations and performance. Specific cost items which could be included here are:

   a. Increases in average trip times resulting from the need to perform more complex switching movements while trains are enroute.

   b. Increased need to pay train crews premium wages due to longer than scheduled trips. Likewise, increased possibility of Twelve-Hour Work Rule being imposed thereby necessitating the call-out of relief crews with associated extra labor costs and traffic delays.

   c. Increased uncertainty in trip times due to decreased ability to "accurately" predetermine the number and complexity of switching movements associated with car set-out and/or pick-up while enroute. May also impact the ability to accurately schedule train "meets" at passing sidings associated with single-tracked lines. This could result in decreased efficiency due to more time spent waiting at such sidings.

   d. Increased need for personnel and for scheduling work assignments so as to effectively and efficiently meet the increased labor/labor hour needs associated with, and resulting from, complying with placement/separation requirements.

3. **Classification Operations.** Costs related to any increase in activities associated with the classification of cars and/or the make-up of trains at yards and terminals in order to conform to in-train placement and separation requirements for hazmat cars. Includes impacts on the utilization of personnel, yard engines, and yard/terminal facilities as they affect the efficiency and cost of classification activities. Specific cost items which could be included here are:

    a. Additional efforts associated with planning and organizing train consists and making up cut lists for the classification process.

    b. Reduction in yard processing capacity due to the additional activities, space, and time required for the handling/ processing of hazmat cars.

    c. Additional yard activities associated with inserting hazmat cars into suitable locations within train consists. This includes disruption of the "normal" process of classifying cars by station destination and forming trains directly from the resulting blocks of cars. Both increases in labor and yard engine usage can be expected.

    d. Increased complexity of operations at intermediate yards where cars are sorted and blocked for incorporation into trains as they pass through. It will become necessary to provide special/extra handling relative to both the classification (in preparation for the arrival of the trains) of hazmat cars, and their eventual insertion into the trains so as to meet hazmat car position/separation requirements.

4. **Over-the-Road-Operations.** Costs related to any increase in activities associated with the over-the-road operation of trains due to impacts associated with hauling and maintaining consists which conform to in-train placement and separation requirements for hazmat cars. Includes all activities (i.e. hauling, pick-ups, set-outs) which take place from the time a train departs its originating terminal until it reaches its final destination. Encompasses all railcar hauling trips: via through trains, local trains, and deliveries/pick-ups by yard crews. Specific cost items which could be included here are:

    a. Additional efforts associated with the set-out and pick-up of cars (both hazmat and others) at spurs, sidings, and intermediate terminals. The probability exists for an increased number of individual switching movements involving increased numbers of cars each time.

b. Additional time spent on passing sidings (on single tracked lines) awaiting the passage of following or opposing priority trains due to potential inability to accurately control trip times and, therefore, meet times.

c. Possible need for more experienced/skilled train engineers to properly handle trains which have poorer derailment dynamics characteristics because hazmat car placement/separation requirements conflict with the judicious placement of loaded vs empty cars.

d. Increased need to double-head helper engines, rather than to employ them as "pushers" when providing helper service, because of increased possibility for hazmat cars being located in the last five positions of trains. This could, depending upon the specific locale and circumstances, result in the need for additional time to couple or remove the helper engines. This could decrease the availability of such engines for other assignments.

e. Increased need to haul additional "extra cars" for the sole purpose of providing the necessary separation of hazmat cars in those cases where the basic train consist does not include a sufficient number of cars suitable for this purpose. The hauling of this extra tonnage would have a negative impact on both fuel consumption and car utilization.

It is recognized that some of the specific cost items associated with each of the four major categories overlap or are in the nature of duplicates. However, it is desirable that each category be able to stand alone. The first addresses the cost of preparing to conform to new in-train placement/separation requirements for hazmat cars. This is primarily a one-time start-up cost, but may involve some continuing expense. The second addresses ongoing day-to-day costs/losses associated with and/or resulting from continued conformance. The third and fourth address the classification/make-up and over-the-road operations, respectively. These two are most directly related to the derailment scenarios of concern here: the former relates to the initial placement/ separation of hazmat cars in trains, while the latter relates to the over-the-road hauling of these cars and, therefore, to the derailments themselves.[6]

The assignment of dollar values to the various cost items must necessarily be based upon tangible items for which quantities and unit costs can be determined. Accordingly, costs must be related to such accountable items as labor hours, equipment usage, fuel consumption, materials used/consumed, and facilities utilization. Likewise, losses must be related to such factors as reduced productivity/capability as evidenced by increased operational costs and/or decreased revenues.

Any determination of the monetary values of benefits and costs for the purpose of comparison and/or estimation of the cost effectiveness of hazmat car placement/separation requirements must recognize the following:

1. It will not be possible to determine, with a high degree of accuracy, dollar values for all benefits and costs. This is due to the intangible nature of some (especially benefits), and the probable lack of detailed accounting data for others (especially costs).

2. The benefits, which are related to <u>expected</u> reductions in costs and losses associated with derailments of trains hauling hazmat, are in the nature of conjecture rather than fact. The determination of the nature and extent of beneficial results cannot be made with certainty, although comparisons of future accident statistics with historical data/trends will be possible. The costs, however, will be real even if they cannot all be specifically identified and/or quantified.

3. Benefits can only arise out of derailments which were avoided or reduced in severity because of hazmat car placement/separation requirements. Therefore, they can only be realized on an occasional basis, with the number of opportunities varying from year-to-year and their magnitude varying from accident-to-accident. Costs will arise both initially (i.e. start-up) and on a continuous day-by-day basis both at the overall operations level and at the individual hazmat train classification/make-up and over-the-road

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6 As noted earlier in this report, while derailments occur during all phases of railroad operations and at all locations, it is the mainline operation of relatively long trains that offers the best opportunity for reductions in derailment severity via car placement and separation strategies.

operations level. Costs are not directly relatable to benefits and would be incurred even if, somehow, no benefits were realized.

It can be expected that performing a detailed cost-benefit analysis will not be a straightforward nor completely conclusive matter. Not only will the process itself entail the use of assumptions and estimates (both relative to the nature of the benefit/cost items, and their monetary value), but there is no assurance that the selected benefits could actually be realized.

5.2 Review of Selected Derailments to Identify Potential for Improved Hazmat Car Placement

Selected railroad accidents were examined and analyzed to determine the extent to which associated derailment effects might have been reduced in severity by "better" placement of hazmat cars within the associated train consists.[7] These accidents were extracted from the set which was reviewed during the conduct of Task Item 1 (see Table 9), and for which NTSB railroad accident reports exist. A mixture of lesser and significant derailments involving hazmat release were selected. It was expected that doing so would provide a range of accident effects and hazmat involvement and would, therefore, be representative of typical hazmat car derailment situations as they presently occur in the United States. The selected accidents/derailments were as follows:

- Fort Knox, Kentucky (3-22-83)
  Illinois Central Gulf Railway Company
- Pine Bluff, Arkansas (6-9-85)
  St. Louis Southwestern Railway Company

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7 The statement of work for Technical Task No. 6 also directed that an attempt be made to identify derailments which might have been avoided by the relocation of hazmat cars. However, as discussed in Section 5.1, it appears that, with possible rare exceptions, derailments cannot be avoided completely by merely repositioning cars within a given train consist.

- Marshville, North Carolina (5-10-84)
  Seaboard System Railroad

- Livingston, Louisiana (9-28-82)
  Illinois Central Gulf Railway Company

These accidents were examined and analyzed in the order shown above. The examinations provided an understanding of the accident and the extent and severity of hazmat involvement; the analyses were concerned with identifying the potential for reducing hazmat involvement by means of the previously discussed in-train hazmat car placement and separation strategies.

The examinations of the accidents/derailments considered the following aspects of the associated scenarios:

1. Nature and extent of the overall derailment.

2. Probable cause of the derailment.

3. Extent of hazmat involvement (number of cars, nature of lading, releases, commingling, etc.).

4. Nature of significant post-derailment effects (fires, explosions, toxic clouds, environmental contamination, etc.).

5. Nature of losses and costs attributable to presence and/or involvement of hazmat (emergency response, population disruption, environmental restoration, etc.).

6. In-train positions of hazmat cars which were involved in the derailment.

7. In-train positions which were not involved in the derailment and whether or not they contained hazmat cars.

8. The train's make-up and activities, relative to the pick-up and set-out of cars, from the time it departed its originating terminal until the derailment occurred.

Overviews of the selected train derailments are presented in Table 14. The descriptions provided are entirely based upon the associated NTSB accident reports, and are necessarily limited in their coverage; for additional detail see the cited NTSB reports. These served

TABLE 14. OVERVIEWS OF CONDITIONS ASSOCIATED WITH SELECTED TRAIN DERAILMENTS INVOLVING HAZARDOUS MATERIALS

1. NTSB/RAR-83/07
Fort Knox, Kentucky, 3-22-83, Illinois Central Gulf Railroad Company.

ICG train SML-4-21, 1st No. 64, engine 702, consisting of four locomotives (at head end) and 78 cars (48 loaded and 30 empty) derailed on curve while moving about 28 mph. NTSB determined the probable cause of the accident to be tipping and breaking of excessively worn, badly shelled curve rail at a point weakened by a detail fracture when it was subjected to normal outward lateral forces.

13 cars (3 tank cars and 10 boxcars) derailed; these were the 33rd through the 45th cars from the locomotive. The 33rd and 34th cars (tank cars containing liquid chloroprene) overturned. Damage to vacuum relief valve on 33rd car permitted discharge into atmosphere at rate of 5 gallons per minute where it gassified. The 35th car ("empty" tank car containing hydrochloric acid residue) also overturned but was not punctured. The remaining ten derailed cars contained inert lading. No data was provided relative to contents of the 65 cars which did not derail (36 loaded and 29 empty) nor the positions of the empty cars. Hazardous materials experts from company owning 33rd and 34th cars stopped the leak approximately 5 hours after derailment occurred. There were no fires and evacuation of the area was not required; there were no injuries. Total damage was estimated at $199,831.

Loaded and empty cars were relatively evenly distributed throughout the train. Initially, the train (with four locomotives, 47 loaded cars, and 41 empty cars) departed Memphis, Tennessee, enroute to Louisville, Kentucky. There was a crew change at Central City, Kentucky. At Cecilia, Kentucky, 17 empty cars and 1 loaded car were set-off and two loaded cars and six empty cars picked-up. The resulting consist was that of the train when it derailed.

2. NTSB/RAR-86/04
Pine Bluff, Arkansas, 6-9-85, St. Louis Southwestern Railway Company

Cotton Belt train Extra 4835 North consisting of six locomotives (located at the head end), 93 cars (90 loaded and 3 empty), and one caboose derailed while passing over a ballast-deck pile trestle. NTSB determined the probable cause of the accident to be (1) failure to destress and adequately anchor the track following hot weather maintenance, and (2) excessive speed and consequential heavy braking on a downgrade in approach to the accident location which compounded the longitudinal stresses imposed on the track structure by the heat.

TABLE 14. (Continued)

2. NTSB/RAR-86/04 (Continued)

At the time of the accident, the train consist included 26 loaded tank cars which were placarded as follows: two as "Dangerous - Flammable Gas", 13 as "Dangerous - Flammable Liquid", two as "Dangerous - Combustible Liquid", three as "Dangerous - Corrosive Liquid", one as "Dangerous - Oxidizer", and five as "Combustible Liquid". These derailed in the quantities 2, 2, 2, 3, 1, and 4, respectively.

Initially, 31 cars (the 26th through the 56th from the locomotives) derailed; subsequent rail rollover derailed 11 more cars (15th through 25th). Of the 42 derailed cars, 18 were loaded tank cars (14 of which contained regulated hazardous or toxic chemical commodities, and four which contained non-regulated flammable petroleum and liquid plastics products). Those tank cars specifically identified by NTSB were: car 20--oil, car 21--butyl methacrylate, cars 22, 24, 32, 33--butyl acrylate, car 23--ethyl acrylate, car 26, 27--vinyl chloride, cars 28, 29--polymethylene polyphylisocyanate (liquid plastic), car 34--acrylic acid, car 36--ethylene oxide, and cars 44, 45--hydrogen fluoride. Initially, the fire was fueled by the release of butyl acrylate from two ruptured tank cars, but spread to pelletized synthetic plastic spilled from covered hopper cars. The fire impinged on an intact tank car (car 36) containing ethylene oxide which exploded about 17 hours after the accident occurred. Later, one of the tank cars (car 28) of liquid synthetic plastic exploded.

Local fire and emergency forces were assisted by railroad and chemical company hazardous material experts. There were fires, and smoke and toxic gasses were released into the atmosphere. Two tank cars (one containing ethylene oxide, the other polymethylene polyphylisocyanate) exploded, but did not rocket. Because of the presence of the ethylene oxide, more than 2,800 persons were evacuated from the area within a 1-mile radius of the derailment. However, no serious environmental problem resulted since most of the hazmat loss was consumed by fire. Damage was estimated at $4,338,000.

The trains point of origin was Shreveport, Louisiana, where it departed with four locomotives, 60 cars (all loaded), and one caboose. At Eagle Mills, Arkansas, two locomotives and 34 cars (31 loaded and 3 empty) were added. The resulting consist was that of the train when it derailed.

3. NTSB/RAR-85/05
Marshville, North Carolina, 5-10-84, Seaboard System Railroad

Seaboard System freight train FERHL consisting of four locomotives (located at head end), 73 cars, and one caboose derailed while moving over a

TABLE 14. (Continued)

3. NTSB/RAR-83/05 (continued)

turnout. The cause of the accident was failure of a freight car axle journal overheating. NTSB determined it was probable that the train crew incorrectly applied information provided to them relative to the overheated journal. Failure of the company to enforce a traincrew monitoring program relative to operating rules was cited as a contributing factor.

At the time of the accident, the train consist included seven loaded cars of hazardous materials. Of them, four were tank cars of methanol; the other were not identified.

Eighteen cars derailed (the 35th through 52nd from the locomotives) starting with the 35th which had the hot journal. The 35th through 37th were carrying pulpwood, the contents of the 38th through 45th were not specified, but the cars were denoted as Hercofina cars (and so probably were carrying chemical products), and the contents of the 38th through 45th were not specified. The derailed cars included four loaded tank cars of methanol and one loaded hopper car of granular plastics (the specific in-train positions of these cars were not specified). During the derailment, the bottoms of two methanol tank cars were torn open and the released methanol ignited. The hopper car of granular plastics was consumed in the fire. One of the other two derailed tank cars of methanol was exposed to the fire and concern over its potential for rupture prompted an evacuation.

The derailment occurred near the Marshville fire department and the county fire marshal happened to be in the area. Therefore, a prompt response resulted, and later included State police, sheriffs personnel, and firefighters from nearby locations. In addition to the evacuation (which involved 2,100 persons from an area within a 1-mile radius of the derailment), a portion of U.S. Highway 74 was closed. The fire was extinguished within 13 hours of the derailment and the evacuation order lifted 3 hours later.

The train crew accepted an inbound freight train at Bostic Yard in Bostic, North Carolina. At that time, 20 loaded coal cars were removed and 18 cars added to the train. The train then consisted of three locomotives, 87 cars, and one caboose. At Stanley, North Carolina, two cars were set out, and at Monroe, North Carolina, 12 cars (1st through 12th cars) were set out and one locomotive added. This resulted in the train consist which subsequently derailed.

TABLE 14. (Continued)

4. NTSB/RAR-83/05
Livingston, Louisiana, 9-28-82, Illinois Central Gulf Railroad Company

ICG train Extra 9629 East (GS-2-38) consisting of three locomotives (located at head end), 100 cars (84 loaded and 16 empty), and one caboose derailed following a sudden emergency brake application. NTSB determined the probable cause of the accident to be the disengagement of a worn air hose coupling in combination with (1) improper response by person at the locomotive controls, and (2) the placement of empty cars near the head of the train between heavily loaded cars.

At the time of the accident, the train consist included 75 tank cars (68 loaded and 7 empty). Of these 55 were placarded as follows: one as "Chlorine", 14 as "Flammable Gas", seven as "Flammable Liquid", one as "Flammable Solid", five as "Poison", and 27 as "Corrosive". These derailed in the quantities of 0, 8, 1, 1, 4, and 13, respectively. In addition, the consist include non-placarded hazmat and flammable petroleum products.

Forty-three cars derailed (the 16th through the 58th from the locomotives). Of these, 36 were tank cars including 27 containing regulated hazardous or toxic chemical commodities, three containing nonregulated hazmat, five containing flammable petroleum products, and one empty. Those tank cars specifically identified by NTSB were: cars 21-25--petroleum, cars 26-32--vinyl chloride, car 33--metallic sodium, car 34--methyl chloride, car 35--perchloroethylene, car 36--tetraethyl lead (motor fuel anti-knock compound), car 39--sodium hydroxide, cars 40-50--phosphoric acid, car 51--hydrofluosilicic acid, car 52--styrene monomer, car 53--empty, cars 54, 56, 57--toulene di-isocyanate, and cars 55, 58--ethylene glycol. Initially, two vinyl chloride cars were breached and escaping gas ignited; this was followed by an explosion. Later, two cars (Nos. 29 and 36) exploded and rocketed. Concern over the stability of several cars resulted in the decision to destroy them by demolition. In all, 36 cars were destroyed by crushing impacts during the derailment or by post-accident fires, explosions, and demolition.

Local fire service forces responded immediately and began extinguishing adjacent fires. Fear of explosion of tank cars subjected to flames prompted an initial evacuation of Livingston (1,260 residents), this was later expanded to include approximately 2,700 persons within a 5-mile radius of the derailment site. Ultimately, the Louisiana State Police assumed control and coordination of the overall response effort. It was 18 days from the day of the derailment until the last derailed cars were removed from the accident site. However, the railroad line remained closed because of the need to excavate 60,000 cubic yards of soil from the site

TABLE 14. (Continued)

4. NTSB/RAR-83-05 (Continued)

(toxically contaminated by perchloroethylene) and truck it to a dump site about 150 miles away.

When the accident occurred, the train had departed Baton Rouge Junction, Louisiana for McComb, Mississippi. The rear 62 cars and caboose were assembled at ICG's Geismar, Louisiana, yard and moved to Baton Rouge as part of another train. It consisted of a forward block of long-haul cars (for Chicago and beyond) and a rear block of short-haul cars (for McComb). The forward 38 cars were assembled at North Baton Rouge Yard and consisted of two blocks; the lead 9 cars routed to McComb and the rear 29 routed to Fulton, Kentucky, for reclassification. These cars were placed ahead of the cars from Geismar by the locomotive and crew and Extra 9629 East.

as a primary basis for the analyses which follow. However, it should be noted that, in some instances, the NTSB reports did not contain the level of detail desired. For example, while it was common practice to cite the car type, lading, and in-train position for all cars which derailed, such information was not usually provided relative to non-derailed portions of the trains. Nevertheless, these reports provided the essential information necessary for the analyses.

The analyses were carried out on an individual accident basis and were primarily concerned with the extent to which the severity of each might have been reduced by "better" in-train placement and separation of hazmat cars. The analyses began with overviews of the hazmat-related damages/expenses to indicate the extent of hazmat involvement and, therefore, the potential for reduction. The actual in-train positions of all cars involved in the derailments (as well as all other hazmat cars to the extent they could be identified) were then determined. The ability to place all hazmat cars (both those which derailed and those which did not) in those segments of the train previously determined to be "safest" was examined. This activity considered the number of hazmat cars, the number of "safe" in-train positions, and whether or not cars in these positions had derailed. Following this, the need for in-train separation of the hazmat cars was considered. This was based upon the specific lading in the hazmat cars and its membership in the previously established chemical groups. Incompatible hazmat cars (i.e., groups) were then identified, thereby establishing the need for separation. The ability to conform to both in-train placement and separation strategies was then examined in light of available "safe" positions. Finally, the basic activities necessary for the railroads to have performed the proposed hazmat car placements, and possible effects upon operations were considered.

5.2.1 Fort Knox, Kentucky Derailment (ICG, 3-22-83)

The Fort Knox, Kentucky, derailment (Item No. 1 in Table 14) can be considered as a relatively minor hazmat accident. While there was a release and "hazardous materials experts" were utilized to stop the liquid chloroprene leak, there were no fires, injuries or evacuation of the area.[8] Also, the listed damage expenses were limited to equipment, track, and signal; no hazmat-related damage was cited. However, there appears to have been hazmat-related expenses in that it was necessary to bring the experts on site, and there were delays in restoring service on the railroad line that probably resulted from deferring wreck clearing activities until the release of hazmat was stopped (this was accomplished five hours after the derailment occurred).

The three derailed hazmat cars were in consecutive positions within the train consist (in-train positions 37-39); this placed them in the middle third/second quarter of the consist. The other ten cars which derailed (positions 40-49) were likewise in the middle third, but extended into the front portion of the third quarter. The 13 derailed cars were, essentially in the middle of the overall consist. The preceding and following positions (positions 5-36 and 50-82, respectively) contained a total of 36 loaded and 29 empty cars which were "evenly distributed".

The cause of the accident was track related and, therefore, independent of the railcars which derailed. It is probable that, regardless of the in-train positioning of cars, those in positions 37-49 would have derailed, with those in the forwardmost positions overturning. Therefore, it can be assumed that the hazmat cars would not have derailed if placed elsewhere. Since there were sufficient positions in the rear quarter of the train (i.e., that quarter which the results of Task Item 1 indicates to be the least likely to derail), the three derailed hazmat cars could have been positioned there, thereby displacing three other cars (probably, in this case, empty cars). Since the contents of the loaded cars in the fourth quarter were not identified, the potential for incompatibility between the subject hazmat cars and possible other hazmat

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8 The AAR Bureau of Explosives' handbook [Ref. Y] indicates that if inhibited chloroprene (flammable liquid) is "leaking (not on fire), downwind evacuation must be considered."

cars positioned in the fourth quarter is not known.

The two hazardous materials involved in the derailment are both members of the top hazardous commodities considered in Task Item 2; chloroprene is ranked 97th and hydrochloric acid is ranked 14th. Further, they are members of Chemical Groups 17 and 1, respectively, which were determined to be incompatible (see Figures 5 and 9). However, in this instance, the hydrochloric acid tank car was classified as an "empty" although it was presumed to contain some residual amount of the acid. If it had been desired to separate this car from the chloroprene cars, it could have been placed in the first quarter of the train (i.e., cars positions 10-20, if it was considered necessary to also separate this car five positions from the locomotive).

The subject hazmat cars were incorporated into the train either prior to its initial departure from Memphis, Tennessee, or during the intermediate stop in Cecilia, Kentucky. It is probable that the two tank cars of chloroprene were being shipped together, but the car of hydrochloric acid residue may have been inserted into the train consist separately. In any event, additional, or perhaps merely different, switching movements could have been readily employed to insert and retain these cars in the rear quarter. This may have increased the complexity of the set-out/pick-up movements required at Cecilia, Kentucky, and had the potential for doing the same at other points along the route to Louisville, Kentucky.

5.2.2 Pine Bluff, Arkansas Derailment (SLSW, 6-9-85)

The Pine Bluff, Arkansas, derailment (Item No. 2 in Table 14) can be considered as a serious hazmat accident. There were fires, explosions, smoke and toxic gases released to the atmosphere, and an evacuation of 2,800 people. Damage expenses (listed as "equipment", "lading", "track", and "bridge") totalled to more than $4 million. Hazmat related costs were not specifically cited, but constituted much of the damage (e.g., released butyl acrylate fueled the initial fire). The presence of hazmat necessitated use of emergency forces for several days, required the presence of hazmat experts, resulted in evacuation costs, and caused delays in restoring service on the line. It appears specific environmental cleanup/restoration efforts were not required.

The 42 derailed cars were in consecutive in-train positions (21st through 62nd), and comprised 42 percent of the 99 total positions (46 percent of the 92 freight car positions). The positions which derailed constituted 39 percent (i.e., 13 of 33) of those available in the first third of the train, and 88 percent (i.e., 29 of 33) of those in the second third; there were no derailments in the rear third. Likewise, the derailed positions constituted 20 percent (i.e., 5 of 25) of those in the first quarter, 100 percent (i.e., all 25) of those in the second quarter, and 64 percent (i.e., 16 of 25) of those in the third quarter. There were no derailments in the rear quarter.

Since the derailment was attributed to track conditions in combination with excess train speed, it can be considered independent of the railcars themselves. Thus, it can be assumed that positions 21 through 62 would have derailed regardless of the specific cars in these positions. And, conversely, any cars in other positions would not have derailed. There were, therefore, 50 railcar positions in which the 26 loaded placarded tank cars could have been "safely" placed.

All of the 26 hazmat tank cars being hauled could have been placed in the "rear" of the train and, in such case, none would have been in positions involved in the derailment. Since this train carried a caboose (in the 99th, and last, position), the five adjacent positions (94th through 98th) could not have been used for placarded cars. However, the four loaded non-placarded tank cars of combustible liquids[9] (at least three of which derailed and one burned and one exploded) could have been placed in these positions. The 26 placarded cars could all have been placed in positions 68 through 93 (possibly, some were). In such case, eight of the cars (those in positions 68-75) would be located

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9 The NTSB Accident Report (NTSB/RAR-86/04) indicated that these were non-regulated commodities such as liquid synthetic plastic.

in the third quarter of the train. However, it is noted that the Task Item 1 findings (see Table 2) show the first quarter to be slightly safer than the third quarter. If this factor was considered, these eight hazmat cars could have been in the first quarter. The presence of six locomotive units and restrictions on placing hazmat within five positions from the locomotive limited available first-quarter railcar locations to positions 12 through 25. Note that positions 21 through 25 derailed which, in this situation, indicates that any hazmat cars in the first quarter should have been located as far forward as possible.

The above discussion on "safe" in-train positioning of the 26 loaded placarded tank cars did not consider further in-train placement considerations associated with restrictions related to the separation of incompatible hazmat commodities. The NTSB Accident Report specifically identified lading in the fourteen which derailed. Of these, thirteen are on the AAR's list of the top 100 hazardous commodities (see Table 11) which were examined in Task Item 2. Additionally, one of the commodities involved in the derailment (two tank cars) is in Chemical Group 1, three (five tank cars) are in Group 13, and one (two cars) is in Group 17. It was previously determined that Groups 1 and 13 are incompatible, as are Groups 1 and 17 (see Table 9). Whether or not there also are incompatibilities between these 14 cars and the other 12 loaded placarded tank cars, or between individual cars within that 12, is not known. However, given the presence of incompatible hazmat commodities and the suggested separation distance for cars carrying such (i.e., 30 car lengths), the placement of the 26 tank cars becomes more involved. Nevertheless, in this instance it would have been possible: the two Chemical Group 1 cars could have been placed in the front of the first quarter (i.e., in positions 12 and 13) and the seven Chemical Groups 13 and 17 in the rear of the last quarter (i.e., in positions 87 through 93). This would have resulted in placements which conformed to both in-train placement and separation guidelines, and which (in this instance) did not derail.

It was noted that the commingling of commodities from placarded tank cars was not cited as a contributing factor in the severity of this accident. However, in large part, the severity was the result of interactions between the contents of placarded and non-placarded cars; the latter being a major contributor to the resulting damage. These interactions were the consequence of both the relative in-train placements of the two types of commodities and the resulting derailment configuration. In this instance, the accordion-like pile-up placed numerous cars in close proximity, thereby readily permitting fires initiated in some to impinge upon others. The in-train hazmat car placement and separation requirements being considered in this study would not preclude such unfavorable placarded versus non-placarded car placements. And, of course, neither derailments nor the dispersion pattern of derailed cars can be predicted. Therefore, no action would have been taken to preclude or mitigate the hazmat versus non-hazmat car interactions which occurred here.

The NTSB accident report did not provide details as to which placarded tank cars were in the original train consist when it departed Shreveport, Louisiana, and which were added at the intermediate stop at Eagle Mills, Arkansas. It can be assumed, however, that more favorable in-train placements could have been effected if such was desired. The number of additional switching movements necessary to do so is unknown, as is the potential effects upon subsequent car set-out activities and terminal destination reclassification activities.

5.2.3 Marshville, North Carolina Derailment (SCL, 5-10-84)

The Marshville, North Carolina, derailment (Item No. 3 in Table 14) can be considered as a moderately serious hazmat accident. There was a release of hazmat material (flammable liquid) which fueled a fire, and concern over the possible rupture of a tank car of the same commodity prompted the evacuation of 2,100 people. One person suffered a minor injury during the evacuation. Damage expenses were listed as \$1,383,000 consisting of railroad equipment (\$931,000), nonrailroad structures (\$277,000), lading and transfer thereof (\$145,000), and emergency response (\$30,000). While not specifically cited, all damage costs associated with the fire, as well as the evacuation, and delays in clearing the wreckage until the fire was extinguished, and the fire-impinged tank car of methanol was judged "safe", can be attributed to derailed hazmat cars. No environmental cleanup was required, however.

The 18 derailed cars were located in consecutive in-train positions (39th through 56th), and comprised 23 percent of the 78 total positions (25 percent of the freight car positions). The positions which derailed constituted 54 percent (i.e., 14 of 26) of those available in the middle third of the train and 15 percent (i.e., 4 of 26) of those in the rear third. Likewise, the derailed positions constituted 5 percent (i.e., 1 of 20) of those in the second quarter and 85 percent (i.e., 17 of 20) of those in the third quarter; there were no derailments in the front and rear quarters.

Since this derailment resulted from an overheated journal bearing on a specific car (in-train position No. 39), it can be assumed that the derailment would have been initiated by this car regardless of its position, and it and some number of following cars would have derailed. The resulting severity would then depend upon the number of cars, the initial damage incurred, and their contents, as it was in the original accident. Since the subject car was not carrying hazmat (it was loaded with pulp wood), there were no restrictions on its placement, nor would there be under any new in-train car placement regulations. In this instance, the initiating car was located approximately mid-train and was one of a group of six pulp wood cars, all of which probably had the same destination. Their placement was probably the normal consequence of building the train in station order to facilitate car set-out/delivery as required. The placement of the hazmat cars was probably for the same reason. Since this derailment was caused by a car-associated mechanical failure, a random event in terms of location in the consist, placement of the hazmat cars in the rear third or rear quarter of the train would not have precluded their derailment.

Methanol is listed as Number 10 on the AAR's list of the top ten hazardous commodities (see Table 11); it is a member of Chemical Group 4. The findings of Task Item 2 indicated that Group 4 is incompatible with Groups 1, 2, 5, 18, 21, and 194 (see Figure 9).

Therefore, it is possible that the four methanol cars would have been incompatible with one or more of the other three hazmat cars, or there could be incompatibilities among the three. In such cases, it would be desirable to apply in-train separation procedures. Because the hazmat under consideration here is not completely known, the need for separation is a matter of conjecture. Assuming there was a need to separate one car, the other six could have been placed as a group at the rear of the train (i.e., in positions 67 through 72), and the incompatible car placed at least 30 car positions away (i.e., position 37 or less). They would have placed this car in the middle third/second quarter of the train and had two positions ahead of the car which initiated the derailment. Since the findings of Task Item 1 indicate that cars in the front of the train are less likely to derail than those in the middle (see Table 2), this car could have been so placed. If multiple incompatibilities had existed, the hazmat car placement and separation requirements would necessarily have been more involved.

Details were not provided as to the point(s) where any of the seven hazmat cars were added to the train. They may have already been entrained when the consist arrived at the Bostic Yard or included in the 18 cars added at this point. In either case, placement of the seven hazmat cars in accordance with the above discussion could have been affected with relatively few additional switching movements. The resulting placements of all cars may have (but probably not) necessitated additional switching at Pinoca Yard where two cars were set out. Similarly, additional switching may have been necessary at Monroe, North Carolina, where the first twelve cars were set out, but, again, probably not. However, at some later delivery point(s), including the unspecified final destination, the need for additional switching would probably occur because of loss of station order positioning of cars, and could be moderately extensive.

5.2.4 Livingston, Louisiana Derailment (ICG, 9-28-82)

The Livingston, Louisiana, derailment (Item No. 4 in Table 14) can be considered as a serious hazmat accident. There were fires and explosions, smoke and toxic gases were released into the atmosphere, two cars exploded and rocketed violently, and about 2,700 persons were evacuated for as long as two weeks. Additionally, nineteen residences and other structures were destroyed or severely damaged, a large quantity of toxic chemicals were spilled (requiring extensive excavation of contaminated soil), and there was long-term closure of the railroad line and an adjacent highway. Damage was listed as $14,564,000 consisting of train equipment ($1,500,000), train loading ($1,013,000), track ($70,000), salvage and wrecking ($32,000) and miscellaneous items ($11,949,000). The latter included evacuation costs, personal injury, property damage claims, along with air, soil, and water treatment, and the excavation and shipment of contaminated soil. Obviously, the vast majority of the overall damage cost was related to the involvement of hazmat in the accident scenario. It should be noted that excavation was very extensive (more than 60,000 cubic yards from a several acre area), and was due to the spillage of 200,000 gallons of toxic chemical product including more than 14,000 gallons of perchloroethylene (tetrachloroethylene) which was considered to be especially harmful.

The 43 derailed cars were located in consecutive in-train positions (19th through 61st), and comprised 41 percent of the 104 total positions (43 percent of the freight car positions). The positions which derailed constituted 49 percent (i.e., 17 of 35) of those available in the front third of the train and 76 percent (i.e., 26 of 34) in the middle third. There were no derailments in the rear third. Likewise, the derailed positions constituted 31 percent (i.e., 8 of 26) of those in the first quarter, 100 percent (i.e., 26 of 26) of those in the second quarter, and 35 percent (i.e., 9 of 26) of those in the third quarter. There were no derailments in the rear quarter.

This derailment was probably initiated by the failure of equipment (i.e., air hose coupling) on a single specific unit. The NTSB accident report indicates that this coupling was probably on the trailing end of the trailing (i.e., 3rd) locomotive. Therefore, the cause of the accident was generally independent of the placement of cars within the train, although possible "unfavorable" positioning of empty cars was cited as a contributing factor.[10] It is not possible to say whether or not the derailment could have been avoided by "better" placement of the empty cars (e.g., place them all toward rear of the train).

There were a large number of placarded tank cars (55) in the consist, and these utilized 61 percent of the 90 in-train positions available to placarded cars; the five positions behind the locomotive and the four in front of the caboose were not available for such use. If the in-train placement strategies discussed in Task Item 1 had been applied, the following situation could have resulted. Of the 55 placarded cars, 20 could have been placed in the rear quarter (positions 79-98), 18 could have been placed in the front quarter (positions 9-26), and the remaining 17 in the rear of the third quarter (positions 62-18). Such placement is based upon utilizing the safer quarters (as identified in Table 2) first. Assuming this redistribution of car placements would not have altered the number or positions of the cars which derailed, those in positions 19 through 61 would still have derailed. Now, there would have been eight derailed placarded tank cars rather than 27 as in the actual accident. If it had been decided to place the 55 placarded cars on the basis of thirds, the following placements might have been employed. Place 29 of these cars in the rear third (positions 70-98) and the remaining 26 in the first third (positions 9-34). Again, assuming the same positions and number of cars derailed, there would have been 16 derailed placarded cars rather than 27.

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10 There were 16 empty cars, most of which were scattered throughout the rear half of the train (4 were just ahead of the caboose in positions 100-103). However, there were 4 empties in the front half (positions 8, 9, 22, and 23) with 32 heavily loaded cars (130 tons or more) located immediately behind the second pair of empty cars. Of the 43 derailed cars, those in positions 22, 23, and 56 were empty.

From the above discussion, it can be seen that a hazmat car place-ment strategy based on either quarters, or thirds probably would have substan-tially reduced the number of hazmat cars which derailed. However, the poten-tial for reduction in the post-derailment effects, and total damage, is less certain as these are also dependent upon the lading in all derailed cars, the damage to these cars, and compounding factors such as fires and explosions.

It is also important to note that the involvement of non-placarded cars in this derailment had a major impact upon post-derailment effects.[11] Lading from two of the five derailed cars of plastic pellets contributed to the initial fires, as did leaking petroleum products from several cars. Similarly, two tank cars of ethylene glycol were derailed and one was breached, losing about 20,800 gallons of its contents. This contributed to the extensive oil contamination problem. More significantly, the tank car of perchloroethylene was damaged and the chemical spilled and absorbed into the ground. This contamination by perchloroethylene was the primary reason why the Louisiana Department of Natural Resources directed that the extensive excavation process be carried out. Since none of these cars were placarded, no effort would have been made to place them in "safe" positions within the train. Indeed, deliberate efforts to so place the placarded cars would increase the probability that these non-placarded cars would then be placed in the "least safe" locations, especially considering the large percentage of placarded cars in the subject train consist. And, in this particular derailment, it was the "least safe" positions which derailed.

Giving attention to additional in-train placement considerations associated with the separation of incompatible hazmat commodities will obviously compound the placement process. Of the 55 placarded cars in the consist, the NTSB report specifically identified

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11 Derailment non-placarded cars included covered hoppper cars of plastic pellets in positions 19, 20, 21, 38, and 39, tank cars of petroleum products in positions 24, 25, 26, 27, and 28, tank cars of ethylene glycol in positions 58 and 61, and the tank car of perchloroethylene in position 38.

the 27 which derailed and indicated the general classifications of the other 28, one of which was "chlorine". Therefore, it can be stated that the following hazmat cars were present: seven cars of vinyl chloride, one car of metallic sodium, one car of methyl chloride, one car of tetraethyl lead, one car of sodium hydroxide, 11 cars of phosphoric acid, one car of hydrofluosilicic acid, one car of styrene monomer, three cars of toulene di-isocyanate, one car of chlorine, and 27 cars of unspecified hazardous materials. Of those materials specifically cited, all except one are on the AAR's list of the top 100 hazardous commodities (see Table 11). The exception is metallic sodium, which is ranked number 101 on this list and was included in the study. It is probable that most, if not all, of the unspecified hazmat cars are duplicates of those which were specified, or are otherwise included in the top 100 listing.

The chemicals in the specified cars are members of several chemical groups (see Figure 5). There was one car in Group 104, one in Group 24, one in Group 21, three in Group 18, eight in Group 17, one in Group 16, one in Group 10, and twelve in Group 1. As indicated in Figure 9, many of these groups are incompatible with one or more of the other groups. Specifically, the following incompatibilities exist: Group 1 is incompatible with Groups 10, 17, 18, 21, and 24; Group 10 with Groups 1, 17, 18, and 21, Group 16 with Group 104; Group 17 with Groups 1, 10, and 104; Group 18 with Groups 1, 10, 21, and 104; Group 21 with Group 1, 10, 18, and 104; Group 24 with with Groups 1 and 104; and Group 104 with Groups 16, 17, 18, 21, and 24. This totals to 14 separate incompatible group pairs. There may well be additional incompatibilities between these 28 hazmat cars and the remaining 27 unspecialized hazmat cars, or between individual cars with the latter group.

A preliminary examination of possible in-train hazmat car placements which utilize the previously discussed "safe" positions and provide for a 30-car separation distance between members of incompatible hazmat groups was conducted. Given the large number of hazmat cars involved here, the known incompatibilities cited above, and the considerable potential for additional incompatible chemical groups and/or cars, it did not prove possible to satisfy both placement strategies. In this case, the inability to provide a 30-car separation distance for all incompatible hazmat cars proved to be the limiting factor. Therefore, while placing hazmat cars in "safe" positions could have been accomplished with seemingly very favorable results, complete separation (i.e., 30-car lengths) of incompatible chemical groups would not have been possible as well. However, it should be noted that the need to do so was not clearly demonstrated: the NTSB accident report did not specifically cite the commingling of hazmat as a significant factor in the resulting extensive damage and expenses.

It appears there was sufficient opportunity at Baton Rouge to place the hazmat cars in the safest available in-train positions. However, the specific amount of "extra" car switching necessary to do so is uncleaar; it may have been considerable. Further, it may have been necessary to wait for the 62 cars and caboose which arrived from the Geismer Yard (via train Extra 8099 North) before the desired placement maneuvers could be initiated. As it was, this entire cut of 62 cars was merely placed behind the two-block cut of 38 cars previously assembled at North Baton Rouge Yard. It appeared that considerable time would have been lost and additional effort required to build ICG train Extra 9629 North in the manner suggested by safe position considerations alone. Also, it would have required considerable more effort if incompatible lading was separated, to the extent possible, as well.

Subsequent impact on switching movements at destination stations (e.g., McComb, Mississippi, and Fulton, Kentucky) could be expected as well. For example, whereas the McComb cars were all situated in the first and last blocks within the consist, the application of hazmat car placement strategies may have resulted in dispersement of these cars throughout the forward and rear portions of the train. In such case, the set-out of the McComb cars would have taken numerous switching movements rather than, say, three. A similar situation would occur at all other stations where cars were picked-up <u>or</u> set-out. It seems clear that with the large number of hazmat cars involved here, there would be a significant increase in the switching movements required at all points along this train's route.

5.3 Considerations Associated With Quantitative Cost/Benefit Analyses

The previously presented analyses of the four derailments involving hazmat cars were, as intended, of an essentially qualitative nature. Consequently, both the effort required and the results derived from these analyses were of a restricted nature. It should be recognized that detailed quantitative cost/benefit analyses can easily require an effort which can be an order of magnitude greater than that utilized here. Not only must all pertinent cost and benefit factors be identified, but costs/losses must be ascribed to each as well. This will require data inputs on a variety of issues and from a variety of sources.

It is, of course, possible to utilize the "damage estimates" given in the NTSB accident reports as a starting point for determining losses due to train derailments involving hazmat. To establish that portion of these losses attributable to hazmat involvement requires reviewing the associated narrative and making appropriate judgments. Some damage categories (e.g., "evacuation", "decontamination") can be essentially attributed to hazmat presence/involvement alone. However, others (e.g., "equipment damage", "lading loss") will require a more careful separation of initial damage resulting from the basic derailment and "additional" damage associated with the involvement of hazmat cars in the derailment scenario.

While the NSTB reports are excellent starting points for identifying the nature of hazmat involvement, as well as the associated losses/costs, the data needs of a detailed quantitative analyses will probably necessitate looking well beyond them. It may be that the related NTSB investigation files, as well as those of the railroad and emergency forces involved, would be available for such use. Other sources of a more general nature maybe available as well. For example, Docket HM-175 [Ref. 26] includes data on unit evacuation costs. Considerable effort may be required to obtain all information necessary to establish a dollar value for the hazmat related portion of the derailment.

Determining the activities, impacts, and costs relating to the in-train placement of hazmat cars according to specific placement strategies can be expected to be even more complex. This work includes determining the number and contents of the hazmat cars in the subject consists. Part, but usually not all, of this information can be found in NTSB's reports. Therefore, other sources of this information must be found. Another area of concern is the amount of, and cost for, the "extra effort" required to build the train with the desired hazmat car placement, operate it over its entire trip, and, finally, reclassify the remaining cars. Of particular interest are the additional switching movements necessitated by the expected loss of conventional train configurations based on station order blocks. The number of these can be estimated from the in-train positions of the cars to be set out at each location, and the placement strategies for cars to be picked up. Determining the costs for such operations, however, is not straightforward. In some, but not all instances, depending upon the length and time duration of the overall trip, there may be specific train crew labor costs associated with each extra switching movement in addition to locomotive usage costs.[3]

It may also be necessary to consider the effects of hazmat car in-train placement strategies upon classification yard operations. Not

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3 A typical switching movement requires 15-20 minutes. In many instances locomotives are leased by the railroads from others. Such leases are based upon horsepower and a 2000 HP locomotive may cost $1500 per day (not including fuel). Through train crews receive basic pay based upon a 100 mile/8 hour trip which may be adjusted for train length as well. Typical rates for working trains of 81 cars and over are: Engineer--$117, Conductor--$108, Brakeman (2 usually required)--$101 (Yard crew rates are slightly higher). If the extra switching movements do not result in the crew working more than 8 hours for the trip, no extra wages will be involved. However, if this is exceeded, the extra time must be paid for at premium rates.

only must the "extra" classification activities associated with the building of specific trains be considered, but it may prove necessary to consider overall yard operations. It appears that such data may not be readily available although this topic was considered as part of an NTSB Special Investigative Report [Ref. 28].

It was not the intent here to provide a detailed discussion of all factors associated with the conduct of a quantitative cost/benefit analysis relative to the subject area. Rather, the purpose was to point out some of the areas to be considered (these were previously addressed in detail in Section 5.1), and provide some insight into the nature and extent of the work involved in conducting such an analysis. And, to provide an appreciation of the rather extensive data needs.

6.0 TASK ITEM 5 -- RECOMMENDATIONS

Task Item 5 was the fifth of the six items which comprise Task Order No. 6. It consisted of a single activity as follows:

> 5-1. Based on the analyses conducted, the Contractor shall make recommendations on the placement of hazardous material cars in a train consist in order to reduce the potential for being involved in a derailment, and, if the cars are in an accident, to reduce the potential for mixtures of incompatible materials.

Since any recommendations must necessarily relate to the "results" and "findings" of the activities associated with Task Items 1 to 4, the most significant of these are presented here first. Following these, the conclusions and recommendations are presented.

6.1 Overview of Results and Findings

The following results and findings are generally presented in the order in which they were addressed in the preceding sections of this report. Some are essentially direct restatements of previously provided items, while others are in the nature of summary and/or conclusion-type statements. These are:

1. Based on Battelle's analysis of RAIRS data for calendar years 1982-1985, the risk of car derailment is significantly less in the rear quarter, or third, of a mainline train. The front sections are the next "safest" position (although marginally so), and the middle sections are the least safe.

2. The primary opportunity for reducing the number and severity of hazardous car derailments by the selective placement of such cars within trains is during the mainline transport of these cars in through train consists. While there are large numbers of derailments in non-mainline situations (e.g., yard operations), they appear to offer relatively little opportunity for employing

significant hazmat car placement strategies beyond those which presently exist.

3. Derailments can be the consequence of several factors which may act alone or in combination to cause an accident. The primary factors are track-related conditions (e.g., a broken rail, "sun kinks" due to high longitudinal compressive stress, poor track geometry), equipment failure (e.g., a broken wheel, an overheated journal), poor train makeup (e.g., unfavorable relative placement of empty and loaded cars), and poor train handling practices (e.g., improper use of throttle and/or brake, or excessive speed). Investigations of some train accidents are unable to establish a specific cause, although "probable" and/or contributing factors are usually cited. Others are able to provide clear identification of cause.

4. Battelle's analysis of the 1982-1985 RAIRS data tended to confirm two derailment-related hypotheses arising from an earlier analytical study. One, increasing the number of cars in a train tends to increase the number of cars which derail should a derailment occur. And, two, increasing the speed of a train increases the number of cars which derail.

5. An examination of the "derailment diagrams" for ten major accidents (all of which involved hazmat cars), indicated that it is common to have groups of cars come to rest in close proximity due to jackknifing and piling of cars. Such groups/clusters may contain a few or numerous cars. One accident had a cluster of 32 cars tightly grouped together. Such groups of cars provide significant opportunities for commingling of hazardous materials, both from the standpoint of opportunity for releases due to initial and/or subsequent derailment damage to any hazmat cars involved, and the opportunity for the released commodities to mix because of the close proximity of the releasing cars.

6. Battelle's analysis of data in FRA's Annual Accident/Incident Bulletins for 1983-1985 showed there was an average of 435 accidents (which include derailments) per year in which the trains involved contained hazmat cars (11.6% of the total number of accidents). There were 53 accidents per year in which a hazmat release occurred. An average of 590 hazmat cars were damaged each year, and an average of 90 cars per year released hazmat. These data imply that an "average" accident of trains carrying hazmat resulted in 1.36 hazmat cars being damaged. In those accidents where releases occurred, (12.2 percent of the total), 1.70 cars released. From this, it appears that instances where released hazmat would commingle would be rare. However, it is recognized that accidents do occur which involve numerous hazmat cars and the release of several hazardous materials.

7. Many hazmat accidents involve only a single hazardous commodity which may release from one or more cars. However, other accidents involve several such commodities and in significant quantities. The presence and, especially, the release of one or more hazmat commodities can result in a considerably worsened accident scenario. Initial or subsequent fires (with harmful combustion effluents) and explosions are commmon consequences. Additional effects include the formation of toxic or combustible vapor clouds: the latter may ignite and/or explode. Also, the heat/flame from initial fires may impinge upon other cars which, depending upon their contents, may later explode and rocket. Not only do these effects result in considerable damage throughout the area of the derailment, but can inhibit fire-fighting, rescue, and/or wreck-clearing activities and necessitate extensive evacuation of the surrounding area.

8. A review of various hazmat accidents as described in NTSB Railroad Accident Reports did <u>not</u> uncover any specific instances where it was reported that <u>actual mixing</u> of released incompatible hazmat occurred and resulted in worsened accident situations or related conditions. However, some of these derailments did involve hazmat cars which

contained groups of commodities which this study subsequently identified as being incompatible.

9. The present U.S. DOT regulations (49 CFR Subpart D) and those of the Canadian Transport Commission (Subpart E, 74.589) pertaining to the placement of hazmat cars within trains are very similar, but not identical. Both relate their specific placement restrictions according to type of car, type of hazardous material, location of people on train, length of train, presence of ignition sources, presence of cars with protruding lading (actual or potential), and presence of other hazmat cars. While the two sets of regulations are generally compatible, it appears that, in some instances, an interchange of consists would require revising the positions of selected hazmat cars. Also, both sets of railroads may need to interpret the placards on cars received and possibly replacard them to conform to practices and regulations pertaining to the receiving railroad. This could result in the need for additional repositioning of cars within the cuts of cars received. However, it appears that reciprocity agreements are in place which facilitate the interchange process and could reduce the need for replacarding and/or repositioning individual cars.

10. The 102 hazardous commodities of interest here (the top 100 given in AAR's "1986 Top 125 Hazardous Commodities Movements by Tank Car Volume" list, plus "sodium metal" and "fuming nitric acid") have a total of 5,151 binary combinations. However, these can be segregated into 28 distinct chemical reactivity groups which have only 378 binary combinations. Incompatibility between these combinations can be identified using the ASTM Hazardous Waste Incompatibility Chart. From this, reactions between specific chemical pair combinations of the incompatible groups can be characterized. It was determined that 1,210 of the 5,151 binary combinations can be judged as "incompatible". Combinations involving non-oxidizing mineral acids (ASTM Chemical Reactivity Group 1), oxidizing mineral acids (Group 2), and caustics (Group 10)

dominate the list of incompatible chemicals. These were involved in 424 combinations (35 percent of the incompatible combinations), 324 combinations (27 percent), and 179 combinations (15 percent), respectively.

11. Since the degree of incompatibility which exists between chemical combinations can vary considerably from pair-to-pair, consequence analyses can be utilized to determine which combinations represent the greatest hazard and risk. A single specific derailment scenario, involving a pair of ruptured, releasing tank cars, can be used to determine the relative consequences of mixing each combination of interest. The primary direct consequences of hazmat mixing are: toxic emissions, fire balls, unconfined vapor cloud explosions, condensed phase explosions, and pool fires. Consequence-based rankings can be used to identify which combinations have the worst consequences, and risk-based ranking can be used to identify which have the worst risk (based upon both consequences and relative frequency of opportunity for occurrence). Consequence can be based upon the size of the surface area above the lethal limit for the pertinent consequences, and frequency can be based upon the yearly number of tank car movements for each chemical of the pair. Combinations/pairs which have consequence or risk rankings above selected levels can be considered to be sufficiently incompatible that action should be taken to preclude their mixing. Categorizing such pairs into their chemical reactivity groups permits matrices of incompatible groups to be developed. The matrix based on consequence rankings contained 94 incompatible group pairs; while that based on risk rankings contained 57 incompatible group pairs. It is felt that mixing of the former (94 combinations) during derailments should be avoided.

12. The most conservative approach to preclude mixing of incompatible hazmat is to separate the associated tank cars so that they would not be involved in the same derailment. However, it is possible to stipulate a representative set of derailment conditions and then

determine the distance a pair of releasing hazmat cars should be separated to preclude or minimize mixing of their contents. For the set of conditions specified, a separation distance of about 40 meters was determined. Because of the close proximity of derailed cars which can result from jackknifing and piling, as evidenced by a very severe derailment involving a "cluster" of 32 cars, an initial estimate of a minimum in-train car separation of 30 railcars was made. This, however, is a conservative estimate. Based on a maximum average of 13 cars derailed (Table 6, page 22) and assumed "stacked" side-by-side, a minimum in-train separation of 15 railcars would provide the recommended 40-meter separation distance to minimize commingling of incompatible chemicals.

13. There are three major car placement factors commonly considered by the railroads when trains are initially made up, or when cars are removed from or inserted into existing train consists. These are: (1) Operational Efficiency, (2) DOT Regulations, and (3) Derailment Dynamics. The first is concerned with facilitating the building of trains as well as their over-the-road operation. The basic goal is to minimize the number and/or complexity of switching movements within terminals and yards, as well as those associated with the transport, set-out, and pick-up of cars while enroute. The second is concerned with conforming to the mandatory DOT regulations concerning the handling of placarded cars as stated in 49 CFR Part 174 Subpart D. The third is directed toward avoiding building trains having inherent dynamic operating characteristics which could promote, or contribute to, derailments. Of these three car placement factors, the railroads give initial consideration and emphasis to the first, Operational Efficiency, the goal being to build and operate trains consisting of blocks of cars in station order. Deviations from this goal are made as necessary to accommodate the DOT's regulations, and, to a much lesser extent, to avoid unfavorable derailment dynamics.

14. There are three major processes which a railcar undergoes from the time it is picked up at the location at which it was loaded (its source) until it is delivered at its ultimate destination. These are: (1) local pick-up and set-out of cars, (2) car classification, and (3) line haul. Operating trains consisting of station order blocks facilitates the process of setting out cars, and is a major factor in the classification process. The number of switching movements required to set-out or pick-up cars from sidings and spurs along a train's route directly impacts the time and effort associated with over-the-road train operations. Trains which have their consists arranged in station order blocks, with that for the first station located immediately behind the locomotive, are considered best suited for efficient operation. The use of station order blocking is a basic and universal railroad practice.

15. Potential additional in-train hazmat car placement constraints are of two separate types: (1) those related to placing such cars in those sections of trains where derailments are least likely to occur, and (2) those related to separating hazmat loads which have been determined to be "incompatible" in order to preclude commingling in a derailment scenario. It is assumed that any placement requirements which might arise from such constraints would be in addition to those already required under current DOT regulations. Neither of the two "new" placement constraints are in conflict with the current in-train car placement regulations. Indeed, the second can be viewed as an extension of existing requirements. However, there is potential for conflict between the two constraints themselves. On one hand, it is desirable to locate all hazmat cars in the rear quarter or third of trains; but on the other hand, separations of many cars may be required between certain of these, thereby limiting the number of available and suitable car positions in the rear. The relatively large number of incompatible pairs, together with the need for large separation distances may at times result in an irreconcilable conflict. The extent to which such conflicts may arise will depend upon the number and nature of the

hazmat cars to be hauled at any given time. This can range from few or none to many with a wide variety of lading.

16. The more requirements imposed upon the railroads relative to in-train car placement, the greater the potential for impact upon their present operational processes. There are a number of areas and processes that would be impacted and, depending upon the amount and type of hazmat actually involved, the impact potential could be very significant. Foremost, any requirements directed toward congregating hazmat cars in specific portions of trains would be in direct conflict with the railroads' practice of grouping cars in destination-specific blocks, and placing these blocks in station order within trains. Further, the basic process of car classification would be complicated as would activities associated with the pick-up and set-out of cars by local or through trains. The loss of the block structure could greatly increase the number of individual switching movements required to perform these functions. In general, implementing and employing the operational changes necessitated by the subject hazmat car placement strategies can be expected to have a negative impact upon operating efficiency and costs. In return, reductions in the number and severity of hazmat car derailments can be expected.

17. The review and analysis of four selected accidents involving the derailment of tank cars and hazmat release indicated that the application of in-train placement and separation strategies for hazmat cars would probably have reduced the number of such cars which derailed and released in those specific instances. Therefore, the resulting overall post-derailment effects, activities and associated costs and losses would probably have been reduced as well. These accidents involved a variety of the set of 102 hazardous commodities studied herein, and there were several instances where members of incompatible chemical groups were involved. However, none of the accident reports cited mixing as a contributing factor to the accident consequences. In these test

cases, a "safe" position for hazmat cars along with a 30-car separation of incompatible pairs was possible only when a few incompatible chemical pairs were in the consist.

18. A preliminary cost/benefit analysis was conducted. The costs of interest here are those associated with effecting the selective in-train position and separation of hazmat cars. These include not only the labor, materials, and equipment usage necessary to do so, but any adverse impacts on railroad operations which may occur in consequence. Benefits include both reductions in the number and severity of derailments involving hazmat, and such other cost savings or improvements that might also result.

19. There is no basis for expecting that the implementation of new in-train placement requirements for hazmat cars will result in a decrease in the total number of derailments occurring in the U.S., or in the total number of cars derailing. What can be expected is a decrease in the number of hazmat cars which derail and, therefore, in the number which release. Hazmat car derailments would not be eliminated since derailments can occur at any position within a train -- there are no "derailment exempt" positions. The selective placement of hazmat cars can merely reduce the probability of their derailment, not guarantee immunity against such. It can be expected that there would be a decrease in the probability of commingling of released incompatible hazardous commodities by virtue of providing suitable separation distances for the associated tank cars.

20. All accidents/derailments will result in some loss/cost whether or not hazmat cars are involved. Initial effects and damage to cars, track, signals, etc., can be expected to be similar, regardless of the contents of the cars which actually derail. However, subsequent effects and related damage can be considerably worse when hazmat is involved. Fires and explosions associated with hazmat can cause additional extensive damage to both railroad property and adjacent properties. The particular effects of a hazmat release

depend on the material and the quantity released, and the overall accident scenario. The extent of economic loss and injury within the adjacent area will depend upon the size of the population at risk which, in turn, relates to the nature of the accident.

21. There is a large range of possible cost items which can be directly associated with railroad accidents. Those items commonly cited under "Damage" in NTSB's Railroad Accident Reports are "train equipment", "train lading", and "track". Others utilized were "bridge", "salvage and wrecking", "nonrailroad", "signals and appurtenances", "lading transfer", "cleanup", "emergency response", "civilian response", "environmental restoration/cleanup", "wreck clearing", "overtime" and "miscellaneous". It appears that the categories employed, and the contents thereof, are selected by the railroad which had the accident and, therefore, provides the cost estimate. In addition, there may be indirect costs such as the loss of the use of the rail line until service can be restored.

22. The beneficial effects of employing in-train hazmat car placement and separation strategies appear to be entirely related to reductions in hazmat involvement and releases and associated detrimental consequences. No operational improvements or other non-derailment related benefits were uncovered. Therefore, the identification of benefits can be primarily based upon the reduction or removal of the differential portions of the losses and costs associated with past derailments involving hazmat which are directly attributable to the presence and/or involvement of the hazmat.

23. In determining whether or not the selective in-train placement and separation of hazmat cars is a cost-effective endeavor, it is desirable to compare the total value of the "benefits" with the total value of the "costs". Therefore it is necessary to ascribe monetary values to all benefit items. In determining these values, it must be recognized that all benefits arise directly from reducing or eliminating hazmat-related post-derailment consequences and

activities. Most potential benefits are of a tangible nature (e.g., reduced loss of lading), but some are not (e.g., adverse publicity). Only specific, directly identifiable portions of the latter can be costed. Therefore, from a practical standpoint, only quantifiable benefits with definite dollar values can be utilized.

24. As with benefits, quantifiable cost items must be identified so that the "costs" associated with the selective in-train placement and separation of hazmat cars can be determined. It is necessary to consider the cost of both the specific activities necessary to conform with additional placement/separation regulations and any negative effects which result from having done so. The various cost items can be separated into four major categories according to the nature of their impact. These are: (1) organization and initiation, (2) overall operation and performance, (3) classification operations, and (4) over-the-road operations, Some of the specific items are "one-time" activities/costs associated with the development and initiation of procedures to conform with the new hazmat car regulations. However, most are of an on-going and continuous nature. Some are of an obvious and direct nature, while others are subtle and indirect.

25. Any determination of monetary values for benefits and costs must recognize the following: (1) it will not be possible to determine, with a high degree of accuracy, dollar values for all items, (2) the benefits will be based upon the expected reductions in derailment-related consequences which are in the nature of conjecture, however the costs will be real, (3) benefits can only arise out of derailments which were avoided or reduced in severity because of placement and/or separation requirements, therefore they can only be realized on an occasional basis, and (4) costs will arise both initially and on a continuous day-to-day basis throughout the railroad industry, and would be incurred even if, somehow, no benefits were realized.

26. It is expected that a detailed, quantitative cost/benefit analysis aimed at determining the cost effectiveness of in-train placement and separation strategies for hazmat cars will require a substantial effort and extensive data input requirements. All pertinent cost and benefit issues and factors must be identified, and specific, tangible costs must be ascribed to each of these.

6.2 Conclusions/Recommendations

The following conclusions and recommendations are directed toward two basic questions:

(1) What in-train placement strategies can be utilized for enhanced safety in movement of hazmat cars, and,

(2) What further activities can assist in determining the advisability of implementing regulations mandating the use of such strategies.

These conclusions and recommendations are based wholly on the work reported in the preceding sections of this report. The order of their presentation is not intended to convey any order of relative importance. In the context of recent regulations governing shelf couplers, head shields, and thermal protection systems, the probability of dangerously incompatible commodities being placed close together in a higher-risk segment of a train, being derailed, punctured and releasing sufficient material to commingle and react, is quite low. Hazmat car placement and separation in a train consist is not seen as particularly cost beneficial. However, to the extent that it can be accommodated, the following recommendations should be followed.

1. Railroad accident data (at least since 1975) indicate that certain in-train locations (car positions) have a lower frequency of derailment than others. Therefore, to reduce the probability of derailment of selected railcars (e.g., hazmat cars), these cars should be placed in these preferred locations. The rear one-quarter

of a mainline train consist is recommended as the most desirable location for hazmat cars, from a derailment-statistics viewpoint. This location will reduce, but not eliminate, the frequency of their derailment, and reduce the probability of hazmat release. The placement of loaded cars in the rear one-quarter may, however, not be advantageous for train handling and dynamics, and in some situations could increase the possibility of derailment. Choice of cars placed in the rear one-fourth or one-third of the consist can be based on the rankings in 49 CFR 173.2(a), except that nonflammable gas should be ranked after flammable liquid.

2. Railroad accident data confirm that, on the average, more cars are derailed in longer trains. To enhance hazmat transportation safety, hazmat cars should therefore be handled in somewhat shorter trains, even though it is recognized that this will result in more trains and possibly increased exposure. Exposure is, of course, route dependent and must be assessed accordingly.

3. Railroad accident data also confirm that, on the average, more cars are derailed in trains at higher speeds. Hazmat cars should therefore be handled at somewhat more restricted speeds. Modest speed reductions may not necessarily result in increased exposure. This is again route dependent.

4. While the potential for the mixing of incompatible hazmat during a derailment certainly exists, such effects were not specifically reported in the accident reports used in this study. From this it could be concluded that mixing of incompatible hazardous chemicals is not a significant problem. However, this report's analysis showed that potentially serious chemical mixing problems were present at several of the railroad accident sites and could have occurred, even though they were not specifically cited in reports of the resulting fires and/or explosions.

5. Optimum hazmat car positioning in a train consist <u>and</u> separation of cars with incompatible chemical groups can impose conflicting requirements in train make-up. This analysis showed the need for at least a 15-car separation between incompatible groups (30 cars as a worst case) in order to minimize mixing. It may be desirable to emphasize <u>position</u>, thereby reducing the number of potential hazmat cars derailing and releasing, rather than <u>separation</u>, which may put hazmat cars into less-optimum train consist locations. We recommend that a separation distance chart be developed based on "worst effect conditions" of mixing of lading. Placarded "Empty" cars may be considered as cars with non-regular material.

6. Hazmat car placement and separation requirements will negatively impact normal railroad operating procedures and efficiencies. Hazmat car placement, instead of the normal practice of building train consists in station-order blocks, will require additional switching moves in classification yards and enroute in pick-up and set-out of cars whenever hazmat cars are involved. Additional switching moves may actually expose hazmat cars to additional potential danger. Cost/benefits of hazmat car placement and separation are difficult to assess: the costs will be real, but the benefits may be elusive.

7. The possibility of utilizing selective application of in-train placement requirements should be considered. This would minimize disruption of normal classification yard and over-the-road train operations when only a few placarded hazmat cars were involved. In-train placement requirements could then be concentrated on specific situations where larger numbers of hazmat cars and more critical combinations of incompatible chemicals were involved. Route sensitivity (e.g., population density, class and condition of track) could be included in this selective application approach.

8. In order to assure that implementation of these requirements on a national scale would, indeed, prove an effective endeavor, a detailed cost/benefit analysis of in-train placement and separation of hazmat cars should be conducted.

REFERENCES

1. Paul Ching-I Fang and H. David Reed, "Strategic Positioning of Railroad Cars to Reduce Their Risk of Derailment", Internal Staff Study, Transportation Systems Center (DOT/TSC), March 1979.

2. P. R. Nayak and D. W. Palmer, "Issues and Dimensions of Freight Car Size: A Compendium", Report No. FRA/ORD-79/56, January 1980.

3. R. G. Powers and J. G. Stephenson, "Trainaction Measurements in the Tropicana Unit Train", ASME Paper No. 73-WA/RT-9, November 1973.

4. W. R. Fahey, et al, "Derailments on a Heavy Haul Railway", Session 315, Paper 3.4, Heavy Haul Railways Conference, Perth, Western Australia, September 1978.

5. T. H. Yang, W. P. Manos and B. Johnstone, "Dynamic Analysis of Train Derailments", ASME Paper No. 72-WA/RT-6, November 1972.

6. American Society for Testing Materials (ASTM), "Proposed Guide for Estimating the Incompatibility of Selected Wastes Based on Binary Chemical Reactions", ASTM D-34, Proposal P 168, 1987.

7. United States Coast Guard, "Chemical Hazardous Response Information System (CHRIS), Hazardous Chemical Data", Commandant Instruction M.16465.12A, 1984.

8. J.P. Flynn and H.E. Rossow, "Classification of Chemical Reactivity Hazards", CG-D-29-74, AD-773049, December, 1970.

9. A.T. Wehman, "The Evaluation of the Test Procedure for Hazardous Binary Combinations of Materials in Marine Transportation", CG-D-85-75, AD-A007915, August, 1974.

10. D. Mackay and R. S. Matsugu, "Evaporation Rates of Liquid Hydrocarbon Spills on Land and Water", Canadian Journal of Chemical Engineering, 51 (1973), 434-439.

11. P. J. Drivas, "Calculation of Evaporative Emissions from Multicomponent Liquid Spills", Environmental Science and Technology 16 (1982), 726-728.

12. U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health, NIOSH Pocket Guide to Chemical Hazards, September, 1985.

13. R. W. Prugh, Evaluation of Unconfined Vapor Cloud Explosion Hazards" in International Conference on Vapor Cloud Modeling, 1987, 712-755, Published by American Institute of Chemical Engineers.

REFERENCES (Continued)

14. A. F. Roberts, "The Effect of Conditions Prior to Loss of Containment on Fireball Behavior", I. Chem. E. Symposium Series No. 71, 181-191.

15. J. Moorhouse and M. J. Pritchard, "Thermal Radiation Hazards from Large Pool Fires and Fireballs - A Literature Review", I. Chem. E. Symposium Series No. 71, 397-428.

16. K. S. Mudan, "Thermal Radiation Hazards from Hydrocarbon Pool Fires", Prog. Energy Combust. Sci. 10 (1984), 59-80.

17. Department of the Army, "Structures to Resist the Effects of Accidental Explosions", Army Technical Manual TM 5-1300, June 1969.

18. P. H. Thomas, "The Size of Flames from Natural Fires", 9th Intl. Symposium on Combustion, 1963, 844-859.

19. K. S. Mudan, "Geometric View Factors for Thermal Radiation Hazard Assessment", Fire Safety Journal, 12 (1987) 89-96.

20. I. Hymes, "Update on the Spanish Campsite Disaster", Loss Prevention Bulletin 061, Published by the Institution of Chemical Engineers, Great Britain.

21. K. G. Brummage, "The Calculation of Atmospheric Dispersion from a Stack", Atmospheric Environment, 2 (1968) 197-224.

22. R. W. Prugh, "Quantitative Evaluation of "BLEVE" Hazards", presented at 1988 AIChE Loss Prevention Symposium, New Orleans, LA, March 8, 1988.

23. "The Effects of a Fire Environment on a Rail Tank Car Filled with LPG", FRA-OR&D 75-31.

24. J. H. Armstrong, The Railroad - What It Is, What It Does, Simmons-Boardman Publishing Co., 1977.

25. P. J. Wong, et al, "Railroad Classification Yard Technology Manual -- Volume I: Yard Design Methods", Report No. FRA/ORD-81/20.1, March 1981.

26. Docket HM-175, FRA-100, "Economic Imapct Analysis of the Retrofit of 105 and 111 Tank Cars Carrying Hazardous Materials", DOT/FRA.

27. Bureau of Explosives, Association of American Railroads, "Emergency Handling of Hazardous Materials in Surface Transportation", 1981.

28. NTSB, "Special Investigation Report: Railroad Yard Safety -- Hazardous Materials and Emergency Preparedness", Report No. NTSB/SIR-85/02, April 30, 1985.