U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

NUREG/CR-7034

Analysis of Severe Railway Accidents Involving Long Duration Fires

Office of Nuclear Material Safety and Safeguards

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Manuscript Completed: November 2010
Date Published: February 2011

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NRC Job Code J5639

Office of Nuclear Material Safety and Safeguards

ABSTRACT

As a regulatory authority for transportation of radioactive materials, the U.S. Nuclear Regulatory Commission (NRC) ensures that packages designed to transport spent nuclear fuel (SNF) meet current regulations. 10 CFR Part 71 provides the regulatory requirements for the certification of transportation packages for SNF and high-level radioactive waste. SNF transportation packages are expected to be designed to endure a fully engulfing fire, as prescribed in 10 CFR Part 71, Section 73. The purpose of the study described in this report was to support NRC in determining the different types and frequency of railway accidents involving severe, long duration fires that could impact rail transport of SNF. Train accident data were examined from both the Federal Railroad Administration and Department of Transportation—Pipeline and Hazardous Materials Safety Administration databases. This study focused on accidents where hazardous material was released from multiple train cars. From this study, the frequency of occurrence of a severe fire was estimated at 6.2×10^{-4} accidents per million freight train-km [1×10^{-3} accidents per million freight train-mi]. None of the accidents examined involved a reported release of radioactive material exceeding the limits set in 10 CFR Part 71. In addition to calculating the frequency, the trends associated with severe fire accidents were determined. In general, severe fires are characterized by derailments in which thousands of gallons of flammable liquid or gas are released. By limiting the SNF package transport to trains that are not also carrying flammable liquid or gas (i.e., to dedicated trains), the likelihood of an SNF transportation package being exposed to a long duration fire would likely be further reduced.

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EXECUTIVE SUMMARY

As a regulatory authority for transportation of radioactive materials, the U.S. Nuclear Regulatory Commission (NRC) ensures that packages designed to transport radioactive material, including spent nuclear fuel (SNF), meet the regulations prescribed in 10 CFR Part 71. In 2003, the National Academy of Sciences (NAS) formed a committee to evaluate risks associated with transportation of SNF and high-level radioactive waste in the United States. The principal findings from this evaluation indicated that there are no technical barriers to safe transport. However, NAS recommended that NRC conduct additional analyses of very long duration fires that could exceed the duration of the hypothetical accident condition fire described in the current regulations. The purpose of the study described in this report was to support NRC in determining the different types and frequency of railway accidents involving severe, long duration fires that could potentially impact SNF rail transport.

To perform this study, railway accidents from the past 34 years (i.e., 1997 to 2008) were analyzed to estimate the frequency of accidents involving hazardous material (HAZMAT) releases. The railway data were obtained from both the Federal Railroad Administration and the Department of Transportation—Pipeline and Hazardous Materials Safety Administration databases. Based on this information, approximately 1,800 accidents involving the release of HAZMAT occurred in the past 34 years, resulting in a frequency of approximately 6.2×10^{-2} accidents per million freight train-km [1×10^{-1} accidents per million freight train-mi]; however, the number of accidents per year has been decreasing, so including all 34 years worth of data may lead to a higher accident frequency than is currently typical. Examining the data during the past 12 years, the frequency is about 60 percent of the 34 years of data at 3.7×10^{-2} accidents per million freight train-km [6×10^{-2} accidents per million freight train-mi].

Most of the report focuses on the review of multiple-car HAZMAT releases because these types of accidents would most likely result in an SNF package being exposed to a fire. The frequency of multiple-car HAZMAT releases resulting in a fire is 1.9×10^{-3} accidents per million freight train-km [3×10^{-3} accidents per million freight train-mi]. In addition, railway accidents for the past 12 years were analyzed in more detail to identify those accidents involving a severe fire and to estimate the accident frequency for a severe fire.

During the last 12 years, 20 railway accidents were identified as having a fire. Out of these 20 fire accidents, only 9 were determined to be severe. The identification of a severe fire was based on (i) the fire being able to fully engulf a railcar for an extended period of time and (ii) the source of fuel for the engulfing fire being derived from another railcar. Using these two criteria, the frequency of a severe fire was calculated as 6.2×10^{-4} accidents per million freight train-km [1×10^{-3} accidents per million freight train-mi]. In addition to calculating the frequency of severe fires, the parameters associated with severe fires were examined. National Transportation Safety Board reports detailed the accidents involving severe fires. Based on this information, severe fires were generally characterized by derailments in which HAZMAT was released from five or more cars. In addition, these HAZMAT releases typically involved the release of thousands of gallons of either flammable liquid or gas.

Based on the analysis of railway accident data, the frequency of severe fire accidents is very small, and therefore, the likelihood of an SNF package being transported on rail that could be affected in a severe fire is also very small. However, limiting the transport of SNF waste packages to dedicated trains that do not carry flammable liquids or gases would likely reduce this likelihood even more.

ACKNOWLEDGMENTS

This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA®) for the U.S. Nuclear Regulatory Commission (NRC) under Contract No. NRC–02–07–006. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of Spent Fuel Storage and Transportation. The report is an independent product of CNWRA and does not necessarily reflect the views or regulatory position of NRC.

The authors would like to thank C. Bajwa and E. Easton for guidance during this study. In addition, the authors would like to thank A. Ghosh for technical review, S. Mohanty for programmatic review, and L. Mulverhill for editorial review. The authors also appreciate A. Ramos and L. Neill for providing word processing support in preparation of this document.

QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: All CNWRA-generated data contained in this report meet quality assurance requirements described in the Geosciences and Engineering Division Quality Assurance Manual. Data used in this report are derived from publicly available sources. Each data source is cited in this report and should be consulted for determining the level of quality of those cited data. Images used in this report that are from the National Transportation Safety Board website are in accordance with National Transportation Safety Board policies provided at www.ntsb.gov/abt_NTSB/policies.htm. In addition, copyright permissions were obtained for the images included in Figures 3-6, 3-7, and 3-11, and attribution was added to the captions of these figures.

ANALYSES AND CODES: Microsoft® Office Excel® 2003 was used to organize the data and macros were written within this software to analyze the data.

REFERENCE

Microsoft. "Microsoft Office Excel 2003." Redmond, Washington: Microsoft Corporation. 2003.

ACRONYMS/ABBREVIATIONS

ANL	Argonne National Laboratory
AAR	Association of American Railroads
CNWRA	Center for Nuclear Waste Regulatory Analyses
DOT	Department of Transportation
EPRI	Electric Power Research Institute
FRA	Federal Railroad Administration
HAZMAT	Hazardous Material
HLW	High-Level Waste
LPG	Liquefied Petroleum Gas
NAS	National Academy of Sciences
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RAB	Railroad Accident Brief
SFST	Spent Fuel Storage and Transportation
SNF	Spent Nuclear Fuel
DOE	U.S. Department of Energy
NRC	U.S. Nuclear Regulatory Commission

1 INTRODUCTION

1.1 Historical Review of Railway Accident Data

The U.S. Nuclear Regulatory Commission (NRC) currently regulates the packaging and transportation of high-level radioactive materials under 10 CFR Part 71. Under these regulations, a spent nuclear fuel (SNF) transportation package must be designed to withstand a sequence of hypothetical accident conditions, including drop, crush (in limited cases), and puncture, followed by an engulfing fire and immersion in water. The current NRC regulations in 10 CFR Part 71 state that an SNF transportation package must be designed to survive a fully engulfing fire with an average flame temperature of at least 800 °C [1,475 °F] for a period of 30 minutes. If subjected to a severe fire, the transportation package must maintain containment, shielding, and criticality functions throughout and after the fire exposure.

In 2003, the National Academy of Sciences (NAS) formed a committee to review the safety of transportation of SNF and HLW. The original purpose of this committee was to evaluate the risks and identify key current and future technical and societal concerns with the transportation of SNF and high-level radioactive waste in the United States. After the study began, the scope of the committee expanded to include the examination of procedures the U.S. Department of Energy (DOE) used for selecting routes for the transportation of DOE research reactor SNF. The review (National Academies Press, 2006) included but was not limited to examination of previous technical studies on package performance, transportation procedures, transportation risk, transportation corridors, and presentations during public meetings.

The principal finding from the NAS committee was that there were no fundamental technical barriers for the safe transport of SNF or high-level radioactive waste. However, the NAS committee indicated that there are social and institutional challenges that require resolution to successfully implement a large quantity shipping program. In addition to this principal finding, the NAS committee indicated that the current international standards and U.S. regulations, at the time of writing the report, are adequate to ensure that the transportation package would provide adequate protection over various transportation conditions. However, the NAS committee did note that various technical reports indicated a very small number of severe accident conditions involving long duration fires could potentially compromise the containment integrity of the SNF package. The committee further recommended that NRC conduct additional analyses of very long duration fire scenarios that bound accident conditions expected to occur under realistic accidents.

Based upon the NAS committee recommendation, the NRC has continued to evaluate accidents that involve severe, long duration fires. This includes the evaluation of the MacArthur Maze fire in April 2007 near the San Francisco-Oakland Bay Bridge in California and the Newhall Pass Tunnel fire that occurred in October 2007 north of Los Angeles, California. In addition to these two accident events, NRC had evaluated long duration fire events before the NAS committee's report was published. These include the Baltimore (rail) tunnel fire that occurred in July 2001 and the Caldecott Tunnel fire that happened in April 1982 near Oakland, California. Out of the four accidents, three were road accidents and one was a railway accident. The results of these accident analyses indicated that the peak temperatures in these fires could have exceeded the 800 °C [1,475 °F] stipulated in 10 CFR Part 71; however, the regulatory temperature is an average temperature (not a peak) and the temperature of the fire is not the only important feature in understanding the implication of these events for SNF transportation. The likelihood that one of these severe accidents could occur in such a way that it might impact the transportation of SNF must also be taken into consideration.

Various studies have reviewed the frequency of accidents involving SNF. NUREG–0170, “Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes” (NRC, 1977), considered two factors in evaluating the impact of accidents involving vehicles carrying radioactive shipments: the frequency of an accident occurring and the consequence of this accident. This report examined the accident rates for aircraft, truck, rail, helicopter, and ship. For rail, fire severity was based upon impact velocity and fire duration at a temperature of 1,027 °C [1,880 °F]. The impact velocities ranged from 0 to 160 km/hr [0 to 100 mph] and were broken into 8 divisions of severity. The fire duration was separated into ½-hour divisions for a total of 2 hours (4 divisions), at an exposure temperature of 1,027 °C [1,880 °F]. At the time NRC (1977) was written, rail shipments of SNF were not expected to be shipped on the same car with other cargo, so the physical process of crushing an SNF package was not considered. Based upon the data Sandia National Laboratories developed, the overall frequency used was 0.93×10^{-6} accidents per railcar-km [1.5×10^{-6} accidents per railcar-mi] or 4.05×10^{-5} accidents per train-km [6.51×10^{-5} accidents per train-mi]. This frequency was based on the assumption that the average train length was 70 cars and that on average, 10 cars would be involved in the accident. Sandia National Laboratories calculated the frequency of different impact speeds based upon examining 700 accidents and calculating the actual impact speeds in SLA–74–001, “Severities of Transportation Accidents, Volume IV–Train” (Larson, et al., 1975). Most of the speeds from this set of 700 accidents occurred at the lower speed range so that the frequencies were extrapolated to the higher speeds where no or little data existed. As such, the accident rates for high speed accidents contained a larger uncertainty and may have affected the overall accident frequency calculations.

Additionally, NUREG/CR–4829, “Shipping Container Response to Severe Highway and Railway Accident Conditions” (Fischer, et al., 1988), evaluated the level of safety provided if a severe accident occurred during the shipment of SNF. The railway accident frequency that was calculated for SNF railway shipments was 7.5×10^{-6} accidents per train-km [1.21×10^{-5} accidents per train-mi]. This frequency was based on using the Federal Railroad Administration (FRA) database information spanning the time mainly between 1979 and 1982. However, for rail-highway crossing accidents, the dates examined included 1975 through 1982. In addition, the frequency of fire occurring from an accident was estimated as 1 percent of the accident frequency. Note that these frequency calculations are based on total FRA freight train data and not just data involving the transport of hazardous waste. Therefore, the additional safety precautions associated with the transport of hazardous waste were not taken into account in these calculations. This report assumed that more than 90 percent of the train mileage is attributed to freight trains so there should be no significant difference in applying these data to estimated accident rates, accident velocities, and fire frequencies.

NRC decided to reexamine the risks associated with the shipment of SNF in NUREG/CR–6672, “Reexamination of Spent Fuel Shipment Risk Estimates” (Sprung, et al., 2000). This report used the same information from NRC (1988) calculating the same frequency, 7.5×10^{-6} accidents per train-km [1.21×10^{-5} accidents per train-mi]. The frequency was again based upon the FRA reported information between 1975 and 1982.

In addition to the work NRC conducted to evaluate frequency of transport accidents involving an SNF package, many other industry studies have analyzed this concern. The Electric Power Research Institute (EPRI) evaluated the frequency of accidents involving railroad material. In “Criticality Risks During Transportation of Spent Nuclear Fuel” (Dykes, 2008), accident frequencies were evaluated using railway accident data from FRA. The EPRI report examined the railway data between January 2000 and May 2006 because (i) railway safety has improved since the 1970s, (ii) FRA reporting structures have changed and improved in the last few years, and (iii) this data range provides separate freight train and passenger train information. From this information, the EPRI report calculated a frequency of 2.7×10^{-6} accidents per train-km [4.33×10^{-6} accidents per train-mi] using total railway data. However, the EPRI report then assumed that total railway data are not as appropriate as using freight train data alone and the accident frequency calculated dropped to 1.7×10^{-6} accidents per train-km [2.67×10^{-6} accidents per train-mi]. EPRI assumed that in accidents where a rail cask could be submerged in water, the train had to have been derailed. This reduced the accident frequency further to 1.4×10^{-6} derailment accidents per train-km [2.25×10^{-6} derailment accidents per train-mi].

In addition, DOE examined the risk associated with transport of SNF in DOE/EIS–0250, “Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada” (DOE, 2002). DOE evaluated its railway freight accidents based upon ANL/ASD/TM–150, “State-Level Accident Rates of Surface Freight Transportation: A Reexamination” (Saricks and Tompkins, 1999). The railroad accident rates were based on Association of American Railroads (AAR) state data from 1994, 1995, and 1996. From the data, the frequency was calculated as 5.39×10^{-8} accidents per car-km [8.67×10^{-8} accidents per car-mi]. Assuming the average number of cars per train is 68, as in NRC (1977), this accident frequency would be 3.7×10^{-6} accidents per train-km [5.9×10^{-6} accidents per train-mi].

A comparison of these previous reports is shown in Table 1-1, which indicates that the earlier studies had a much higher accident frequency per train mile than the later studies. This is likely a result of the changes in railway regulation that have increased the safety of train travel over the past 30 years. This information is further discussed in Chapter 2. Except for NRC (1977) and DOE (2002), the main source of information is FRA. As shown in Table 1-1, the accident frequency changes depending upon the timeframe examined with lower frequency in more recent years.

Table 1-1. Comparison of Railway Accident Frequencies

Source Document	**Source of Data**	**Reported Accident Frequency (Accidents/Train-Mi)***
NUREG–0170 (NRC, 1977)	Severity of Transportation Accidents, SLA-74-001 1975	6.51×10^{-5}
NUREG–4829 (Fischer, et al., 1988) and NUREG–6672 (Sprung, et al., 2000)	FRA Rail Data 1975–1982	1.21×10^{-5}
DOE/EIS–0250 (DOE, 2002)	AAR State Data 1994–1996	5.90×10^{-6}
(Dykes, 2008)	FRA Rail Data 2000–2006	4.33×10^{-6}

*To convert to accidents/train-km, divide by 1.609.

NRC has conducted a preliminary investigation to examine historical railway accidents that would have potentially affected an SNF package in order to understand potential accident trends. This information was presented in NUREG/CR–6886, “Spent Fuel Transportation Package Response to Baltimore Tunnel Fire Scenario” (Adkins, et al., 2006). This document examined the fire characteristics and initiated a review of railway transportation accidents. Adkins, et al. (2006) reviewed the FRA data between 1975 and 2005 and noted that there were 1,700 accidents involving HAZMAT release during these railway accidents. Of those accidents, the document highlights eight accidents because of the quantity of flammable material released and the relatively long fire duration. Even though the highlighted eight accidents were deemed significant, the conclusion was that seven of these could not have provided a fully engulfing fire environment for the SNF package because of three factors: (i) the transportation package would not have been located close enough to the fire, based on the Department of Transportation (DOT) regulations at the time related to spacing of railcars; (ii) the majority of the fires resulting from accidents involved gasses that would not result in pooling; and (iii) the emergency response time was rapid enough to minimize fire intensity. Only the Baltimore tunnel fire provided unique factors, such as location (in a tunnel) and the duration of the fire, that might have exposed an SNF transportation package to a pooling fire (had one been involved in that particular accident). Adkins, et al. (2006) indicated, however, that the probability of such an accident occurring and involving an SNF transportation package would be extremely low.

1.2 Objective

The objective of the study documented in this report is to support the NRC Division of Spent Fuel Storage and Transportation (SFST) in conducting an assessment of severe railway transportation accidents involving long duration fires. SFST is responsible for developing and implementing NRC programs governing storage and transportation of SNF. To support the SFST mission, the Center for Nuclear Waste Regulatory Analyses (CNWRA®) was tasked to review available data on derailments of trains carrying flammable HAZMAT that resulted in a long duration fire, update the railway accident statistics, and assess possible trends associated with railway accidents involving long duration fires.

1.3 Scope and Organization of the Report

As will be described in Chapter 2 of this report, roughly 1,800 reported accidents occurred between 1975 and 2008 that involved the release of HAZMAT. Many of these were minor releases, and only one involved radioactive material. Analyzing the railway accident statistics and determining whether there are any trends in the data can support NRC evaluations of current and future regulations associated with SNF transportation.

This report focuses on the statistics and trends of historical railway accident data. The document is organized into four chapters, including this chapter (Chapter 1, Introduction). The review of historical railway accident data is discussed in Chapter 2. Chapter 2 evaluates accident frequency from FRA and Pipeline and Hazardous Materials Safety Administration (PHMSA) accident data and examines the trends associated with these data. Chapter 3 narrows down this accident list to focus on the evaluation and trends of accidents involving severe fire. Chapter 4 presents conclusions from this study.

2 DATA ANALYSIS

The Federal Railroad Administration (2003) defines an accident/incident in terms of a list of reportable events. The list includes fatalities, injuries, illnesses, collisions, derailments, and impacts. In addition, the FRA specifies reportable damage above a threshold amount.[1]

Accidents/incidents are further categorized as (Federal Railroad Administration, 2003)

- Train Accident: "Any collision, derailment, fire, explosion, act of God, or other event involving the operation of on-track equipment (standing or moving) that results in total damages to all railroads involved in the event that is greater than the current reporting threshold to railroad on-track equipment, signals, track, track structures, and roadbed."
- Train Incident: "An event involving the movement of on-track equipment that results in a reportable casualty but does not cause reportable damage above the threshold established for train accidents."
- Nontrain Incident: "An event that results in a reportable casualty, but does not involve the movement of on-track equipment nor cause reportable damage above the threshold established for train accidents."

In this report, the term "accident" is used regardless of the reportable damage being above or below the threshold established for train accidents. Accidents were identified regardless of the cause in which a HAZMAT release occurred during transfer of HAZMAT on a railway. For example, accidents were identified in which a single train derailed and accidents in which a train collided with an object (e.g., a backhoe left on the track by vandals) or another train.

The review focused on HAZMAT release accidents involving multiple cars to identify those involving a fire. This review identifies the HAZMAT class involved and the amount of HAZMAT released; Appendix A lists accidents on the main line, and Appendix B lists accidents off the main line. These appendices show the types and amounts of flammable materials and oxidizers released for the accidents identified. The following sections include the analysis for HAZMAT release accidents and identify the data sources, the method for screening the data, overall accident frequency, and the means for grouping the data or classifying accidents in terms of where the accidents occurred (e.g., main line or yard), what characteristics were associated with the accidents (e.g., speed of the train or class of track), what HAZMAT was involved (e.g., HAZMAT Class 3 flammable liquid), and what type of accidents occurred (e.g., collision or derailment).

2.1 Data Sources

The main sources of data used in this study were FRA data and HAZMAT accident data developed by the U.S. Department of Transportation—Pipeline and Hazardous Materials Safety Administration, Office of Hazardous Materials Safety. Microsoft® Office Excel® 2003 was used to compile the FRA and HAZMAT information into spreadsheets that could be queried via standard filtering and sorting tools and macros.

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[1]As described in Chapter 2 of Federal Railroad Administration (2003), the reporting threshold has changed over the timeframe of this study. For example, the reporting threshold increased from $6,300 in calendar years 1991–1996 to $6,700 in calendar years 2002–2003.

2.1.1 Federal Railroad Administration Database

Each year FRA collects data from more than 600 railroads as part of its regulatory and enforcement responsibilities (Federal Railroad Administration, 2003). The database of railroad accidents from 1975 to 2008 was obtained in an uncompressed Excel (XLS) format from the Federal Railroad Administration Office of Safety Analysis (2010). Specifically, data for all the accidents are found under Section 3.03, Download Accident Data. Each data file includes any reported collision, derailment, fire, explosion, act of God, or other event involving the operation of railroad on-track equipment and involving damages exceeding the reporting threshold for the year reported (Federal Railroad Administration, 2003).

2.1.2 Pipeline and Hazardous Materials Safety Administration Database

The number of accidents involving HAZMAT and the number of accidents resulting in a fire were calculated using data acquired from PHMSA. Ten years of data were downloaded in Excel format from Pipeline and Hazardous Materials Safety Administration (2010; only the "in transit" accidents were selected). Railway accidents for 1997 were requested directly from PHMSA because they could not be downloaded directly from the website.

2.2 Data Screening

This study using FRA data initially focused on identifying (i) the number of railroad accidents that led to a release and (ii) the number of railcars that were involved in that release. More cars involved in a release can potentially lead to more significant events that should be evaluated given that, in many of the cases involving multiple-car HAZMAT releases, thousands of gallons of flammable liquid or gas were released. Specifically, the process for evaluating this data is described next:

- FRA data were obtained per year, and the database records were sorted by the number of cars releasing HAZMAT.
- Once sorted, the records with no release of HAZMAT were removed.
- Duplicate records were identified using incident number, date, railroad division, and location of the incident. This identification was done so that accurate values could be developed for number of HAZMAT cars releasing.
- Two distinct data sets were developed: one for single-car HAZMAT releases and the other for multiple-car HAZMAT releases.
- An indication of whether a fire had occurred was determined by examining the FRA description of the accident.
- For some accidents, the FRA information did not describe a fire. In those cases, the FRA accident data, where a HAZMAT release occurred, were also compared to the PHMSA database using dates and locations. If FRA and PHMSA data matched, the PHMSA data were also used to identify whether a fire had occurred during a railway accident.

2.3 Overall Frequency of Railway Accidents

Table 2-1 summarizes the railway accidents for the past 34 years (i.e., 1975 to 2008) to include those involving a HAZMAT release. The frequencies in this table are the number of accidents divided by the total freight train distance traveled. For example, the frequency for freight train accidents in 1975 is 6.4 accidents per million freight train-km [10.35 accidents per million freight train-mi] obtained by dividing 5,906 freight train accidents by 917 million freight train-km [570 million freight train-mi]. The accidents involving a HAZMAT release are shown in the right in the table separated by single-car and multiple-car HAZMAT releases. The cumulative values for all 34 years are shown in the last row of the table.

Table 2-1. Summary of Railway Accidents From 1975 to 2008

Year	Million Freight Train Miles*	Total Freight Train Accidents		Accidents with Release of HAZMAT					
				Total		Single Car		Multiple Car	
		Number	Frequency†	Number	Frequency†	Number	Frequency†	Number	Frequency†
1975	570	5,906	10.35	83	0.15	62	0.11	21	0.04
1976	585	7,187	12.28	113	0.19	88	0.15	25	0.04
1977	566	7,192	12.70	114	0.20	86	0.15	28	0.05
1978	568	7,512	13.23	138	0.24	102	0.18	36	0.06
1979	577	6,475	11.23	105	0.18	81	0.14	24	0.04
1980	542	5,339	9.85	119	0.22	94	0.17	25	0.05
1981	511	3,617	7.08	77	0.15	60	0.12	17	0.03
1982	433	2,903	6.70	59	0.14	39	0.09	20	0.05
1983	422	2,598	6.16	52	0.12	45	0.11	7	0.02
1984	448	2,642	5.90	54	0.12	40	0.09	14	0.03
1985	431	2,230	5.17	54	0.13	41	0.10	13	0.03
1986	428	1,894	4.42	51	0.12	39	0.09	12	0.03
1987	439	1,842	4.20	50	0.11	34	0.08	16	0.04
1988	460	1,936	4.21	44	0.10	29	0.06	15	0.03
1989	469	1,996	4.26	56	0.12	38	0.08	18	0.04
1990	460	1,941	4.22	35	0.08	19	0.04	16	0.03
1991	436	1,774	4.07	47	0.11	31	0.07	16	0.04
1992	448	1,539	3.43	27	0.06	22	0.05	5	0.01
1993	464	1,634	3.52	29	0.06	21	0.05	8	0.02
1994	495	1,578	3.19	36	0.07	30	0.06	6	0.01
1995	506	1,578	3.12	27	0.05	19	0.04	8	0.02
1996	507	1,559	3.08	34	0.07	24	0.05	10	0.02
1997	512	1,529	2.98	31	0.06	25	0.05	6	0.01
1998	520	1,612	3.10	42	0.08	28	0.05	14	0.03
1999	542	1,609	2.97	41	0.08	32	0.06	9	0.02
2000	549	1,763	3.21	35	0.06	23	0.04	12	0.02
2001	538	1,773	3.30	32	0.06	17	0.03	15	0.03
2002	547	1,562	2.86	31	0.06	22	0.04	9	0.02
2003	561	1,618	2.88	30	0.05	25	0.04	5	0.01
2004	584	1,810	3.10	31	0.05	21	0.04	10	0.02
2005	597	1,712	2.87	39	0.07	29	0.05	10	0.02
2006	624	1,622	2.60	30	0.05	19	0.03	11	0.02
2007	586	1,465	2.50	46	0.08	34	0.06	12	0.02
2008	565	1,290	2.28	22	0.04	16	0.03	6	0.01
Cumulative	17,489	92,237	5.27	1,814	0.10	1,335	0.08	479	0.03

*To convert to kilometers, multiply by 1.609.
†Frequency in accidents per million freight train-mi. To convert to accidents per million freight train-km, divide by 1.609.

To identify severe fire accidents, the review focused on multiple-car HAZMAT releases instead of single-car HAZMAT releases because larger amounts of flammable materials are more likely to be released in multiple-car accidents than in single-car accidents. The last 12 years (i.e., 1997 to 2008) were analyzed in terms of multiple-car HAZMAT releases in Section 2.4 and are included in Table 2-2. Those multiple-car HAZMAT release accidents involving a fire were identified for the last 12 years and are shown in the rightmost columns in the table. As described in the flowcharts shown in Figure 2-1, the percentage of releases resulting in a fire was significantly higher for multiple-car HAZMAT releases, and therefore, multiple-car HAZMAT releases were reviewed in detail to identify accidents resulting in a severe fire.

Table 2-2. Summary of Railway Accidents From 1997 to 2008

Year	Million Freight Train Miles*	Total Freight Train Accidents		Accidents with Release of HAZMAT							
				Total		Single Car		Multiple Cars			
										Involving Fire	
		Number	Frequency†	Number	Frequency†	Number	Frequency†	Number	Frequency†	Number	Frequency†
1997	512	1,529	2.98	31	0.06	25	0.05	6	0.01	0	0.000
1998	520	1,612	3.10	42	0.08	28	0.05	14	0.03	2	0.004
1999	542	1,609	2.97	41	0.08	32	0.06	9	0.02	0	0.000
2000	549	1,763	3.21	35	0.06	23	0.04	12	0.02	2	0.004
2001	538	1,773	3.30	32	0.06	17	0.03	15	0.03	2	0.004
2002	547	1,562	2.86	31	0.06	22	0.04	9	0.02	0	0.000
2003	561	1,618	2.88	30	0.05	25	0.04	5	0.01	2	0.004
2004	584	1,810	3.10	31	0.05	21	0.04	10	0.02	1	0.002
2005	597	1,712	2.87	39	0.07	29	0.05	10	0.02	2	0.003
2006	624	1,622	2.60	30	0.05	19	0.03	11	0.02	1	0.002
2007	586	1,465	2.50	46	0.08	34	0.06	12	0.02	5	0.009
2008	565	1,290	2.28	22	0.04	16	0.03	6	0.01	3	0.005
Cumulative	6,725	19,365	2.88	410	0.06	291	0.04	119	0.02	20	0.003

*To convert to kilometers, multiply by 1.609.
†Frequency in accidents per million freight train-mi. To convert to accidents per million freight train-km, divide by 1.609.

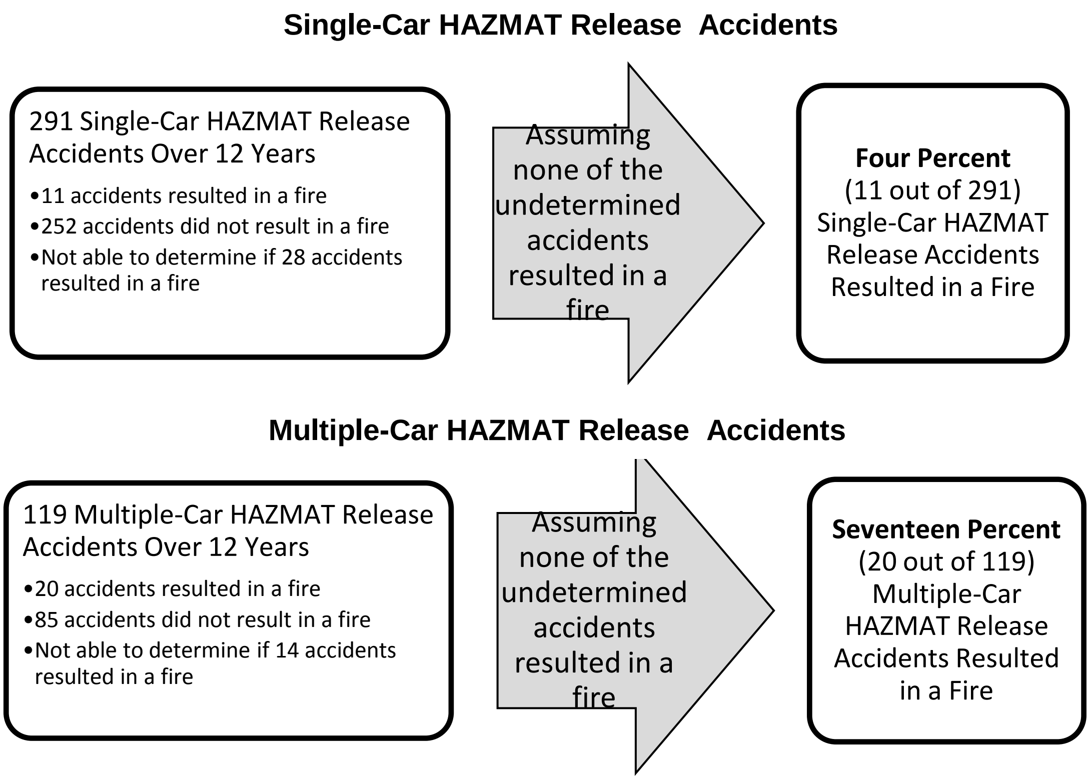


Figure 2-1. Data Analysis for Single-Car and Multiple-Car HAZMAT Release Accidents

As shown in Tables 2-1 and 2-2, accident frequencies, in general, have decreased over time. For accidents with release of HAZMAT, the total frequency for the past 12 years {i.e., 3.7×10^{-2} accidents per million freight train-km [6×10^{-2} accidents per million freight train-mi]} is approximately 60 percent of the total accident frequency for the entire 34 years {i.e., 6.2×10^{-2} accidents per million freight train-km [1×10^{-1} accidents per million freight train-mi]}. The single-car and multiple-car HAZMAT release accidents are shown separately in the tables. The frequencies for these accidents show similar decreases in the last 12 years when compared to their accident frequencies over the entire 34 years. As described in Section 2.4, the 119 multiple-car HAZMAT release accidents for the past 12 years are divided between 89 accidents that occurred on the main line and 30 accidents that occurred off the main line in an industrial area, rail yard, or siding. As shown in Table 2-2, the accident frequency for multiple-car HAZMAT release accidents involving a fire is approximately 1.9×10^{-3} accidents per million freight train-km [3×10^{-3} accidents per million freight train-mi], which is about 15 percent of the accident frequency for multiple-car HAZMAT release accidents over the same 12-year period. Multiple-car HAZMAT release accidents are further analyzed in Section 2.4.

Considering the summary values in Table 2-1, the HAZMAT release accident frequency is approximately 2 percent of the total accident frequency. The multiple-car HAZMAT release accident frequency is approximately 0.6 percent of the total accident frequency. Based on the information in Table 2-2, the accident frequency for those multiple-car HAZMAT releases resulting in a fire {i.e., 1.9×10^{-3} accidents per million freight train-km [3×10^{-3} accidents per million freight train-mi]} is estimated to be approximately 0.1 percent of the total accident frequency {i.e., 1.8 accidents per million freight train-km [2.88 accidents per million freight train-mi]}; however, as described in Section 2.4 and shown in Table 2-2, the accident frequency for multiple-car HAZMAT releases resulting in a fire has increased in the last 2 years (i.e., 2007 and 2008). Specific causes for this increase were not identified in this study.

Figure 2-2 shows the accident frequency trends for the past 34 years. This figure shows that the total accident frequency, HAZMAT release accident frequency, and multiple-car HAZMAT release accident frequency has a decreasing trend for the past 34 years.

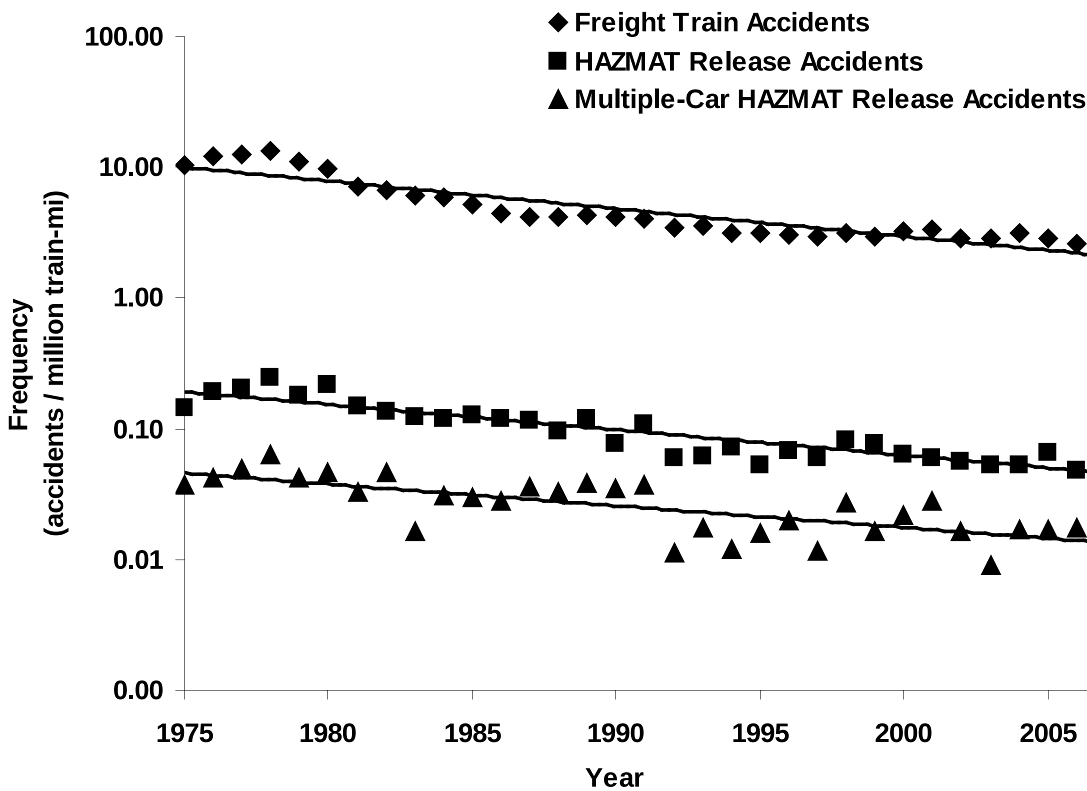


Figure 2-2. Frequency of Railway Accidents From 1975 to 2008

2.4 Data Classification for Multiple-Car Hazardous Material Release Accidents

The FRA and PHMSA data were reviewed for railway accidents that occurred from 1997 to 2008 to determine the parameters associated with the accidents (e.g., speed and number of cars derailed) and to identify the HAZMAT involved. These data sources are described in Section 2.1. As shown in Figure 2-3, out of 119 multiple-car HAZMAT releases accidents (Table 2-2), 89 were identified on the main line and 30 were identified off the main line.

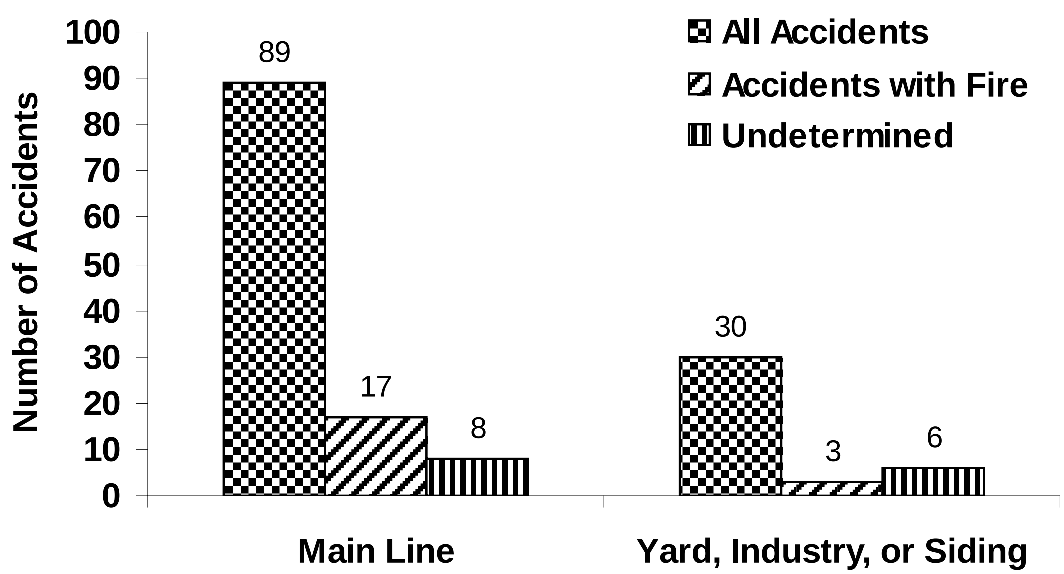


Figure 2-3. Multiple-Car HAZMAT Release Accidents From 1997 to 2008

For the 89 accidents occurring on the main line, 17 resulted in a fire. For the 30 accidents occurring off the main line, 3 resulted in a fire. It was not clear from the data whether a fire resulted in 8 out of the 89 accidents on the main line, nor was it clear from the data whether a fire resulted in 6 out of the 30 accidents off the main line. Accident parameters and HAZMAT involved are described in this section and listed for the 89 accidents on the main line and 30 accidents off the main line in Tables A–1 and B–1, respectively, of Appendices A and B. Section 3.4 further describes those parameters associated with severe accidents.

As shown in Figure 2-4 involving main line accidents, less than 25 percent (i.e., 21 out of 89) of the multiple-car HAZMAT release accidents occurred in the last 3 years (i.e., 2006 through 2008); however, almost half (i.e., 8 out of 17) of the HAZMAT release accidents involving a fire occurred in the last 3 years.

On average, for the 12 years from 1997 to 2008, between 7 and 8 multiple-car HAZMAT release accidents occurred per year, and the number of accidents for 2007 and 2008 fell just above or just below the average (i.e., 9 for 2007 and 5 for 2008). Assuming none of the 8 undetermined accidents resulted in a fire, then for the 12 years from 1997 to 2008, on average, 1 to 2 multiple-car HAZMAT release accidents resulted in a fire per year. For the years 2007 and 2008, the number of these fire accidents was more than twice the average (i.e., four for 2007 and three for 2008).

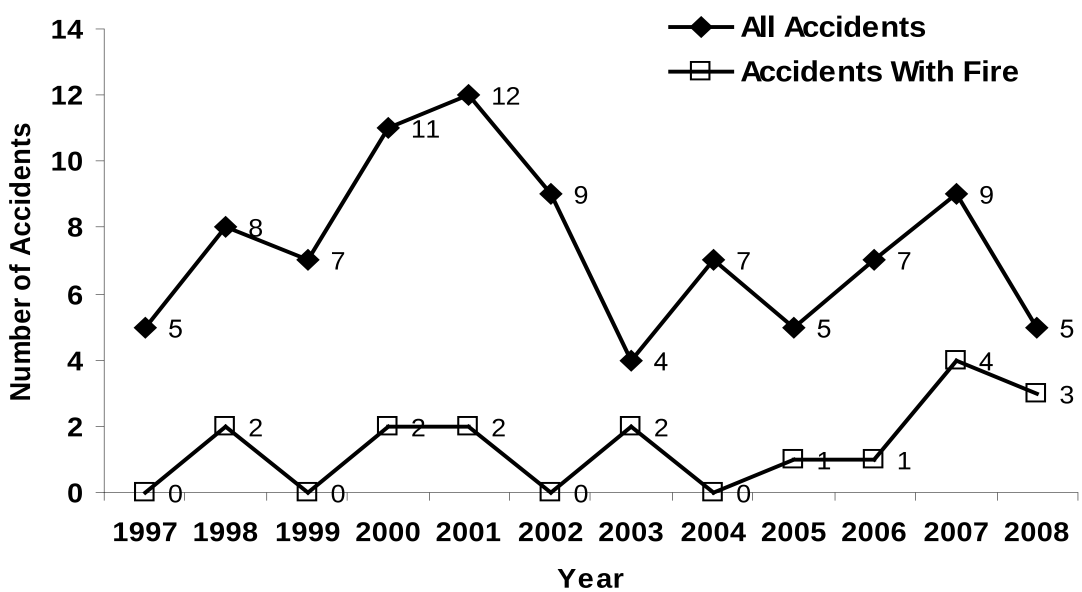


Figure 2-4. Number of Multiple-Car HAZMAT Release Accidents and Multiple-Car HAZMAT Release Accidents Resulting in a Fire by Year

Table 2-3 lists the multiple-car HAZMAT release accidents that resulted in a fire. The 17 accidents that occurred on the main line are listed in the upper portion of the table, and the 3 accidents that occurred off the main line are listed in the lower portion of the table. Table 2-3 shows the type of accident (i.e., derailment or collision), the HAZMAT class, the number of HAZMAT cars on the train and the number of HAZMAT cars releasing. The accidents listed in this table are referred to in the following subsections.

Table 2-3. Multiple-Car Release Accidents Resulting in a Fire

Date	Location	Type of Accident	HAZMAT Cars		Track*	HAZMAT Class†
			Total	Releasing		
On the Main Line						
12/7/2008	Nolan, ND	Derailment	24	6	m	2.1, 3
10/23/2008	Caney, OK	Derailment	29	3	m	2.2, 3
8/22/2008	Luther, OK	Derailment	13	5	m	3
12/28/2007	New Florence, PA	Derailment	17	2	m	3
10/10/2007	Painesville, OH	Derailment	40	5	m	3, 9
03/12/2007	Oneida, NY	Derailment	42	6	m	2.1, 3, 8
1/16/2007	Brooks, KY	Derailment	15	7	m	2.1, 3, 8, 9
10/20/2006	New Brighton, PA	Derailment	80	20	m	3
7/10/2005	Anding, MS	Head-on Collision	13	2	m	2.1, 3
10/25/2003	Shorters, AL	Derailment	43	3	m	3, 5.1
2/9/2003	Tamaroa, IL	Derailment	50	7	m	2.1, 3, 8
8/30/2001	Mulvane, KS	Obstruction	10	3	m	3, 9
7/18/2001	Baltimore, MD	Derailment	9	4	m	3, 8
12/18/2000	Plymouth, MN	Derailment	102	6	m	4.1
5/27/2000	Eunice, LA	Derailment	56	18	m	2.1, 2.3, 3, 6.1, 8
9/2/1998	Crisfield, KS	Derailment	5	3	m	3, 6.1, 8
6/26/1998	Niota, IL	Side Collision	6	4	m	3, 8
Off the Main Line						
10/22/2007	Middlebury, VT	Derailment	15	4	y	3
1/8/2005	Seabrook, TX	Derailment	13	2	i	3, 5.1
9/21/2004	East St. Louis, IL	Other Impacts	3	2	y	3

*****Track: m = main, i = industry, y = yards, s = siding
†HAZMAT Class: 2.1 = Flammable Gas, 2.3 = Poisonous Gas, 3 = Flammable Liquid, 4.1 = Flammable Solid, 5.1 = Oxidizer, 6.1 = Poison, 8 = Corrosive Material, 9 = Miscellaneous

2.4.1 Number of Cars Releasing HAZMAT

As shown in Figure 2-5 for accidents on the main line, generally seven or fewer cars released HAZMAT in an accident.

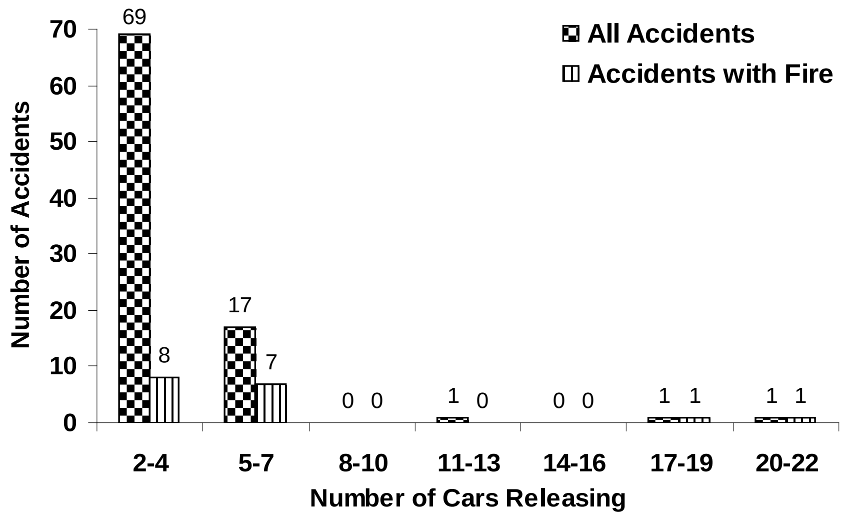


Figure 2-5. Number of Cars Releasing HAZMAT in Multiple-Car HAZMAT Release Accidents on the Main Line From 1997 to 2008

There were three exceptions. Eleven cars released HAZMAT in one accident that did not involve a fire. In this accident, HAZMAT Class 2.2 anhydrous ammonia (i.e., nonflammable gas) was released from the 11 cars. In 2 other accidents, fires occurred with the release from 18 cars and 20 cars. Assuming none of the 8 undetermined accidents resulted in a fire, Figure 2-5 shows that a fire occurred less than 12 percent of the time (i.e., 8 out of 69 accidents) when 4 or fewer cars released HAZMAT, but occurred 45 percent of the time (i.e., 9 out of 20 accidents) when HAZMAT was released from 5 or more cars.

2.4.2 HAZMAT Class

Figure 2-6 displays the multiple-car HAZMAT release accidents for HAZMAT classes involving flammable materials and oxidizers. The amount of flammable materials and oxidizers released in these accidents is listed in Appendix A, Table A–1. As shown in Figure 2-6, Class 3 HAZMAT (i.e., flammable liquid) was released in more than half of the 89 accidents (i.e., 47 out of 89) and in all but one of the accidents that resulted in a fire (i.e., 16 out of 17). This one accident for which Class 3 HAZMAT was not identified instead involved Class 4.1 HAZMAT (i.e., flammable solid) and occurred on December 18, 2000, in Plymouth, Minnesota. In this accident, approximately 72,000 L [19,000 gal] of molten sulfur were released from 6 cars.

In some accidents, such as the one occurring on October 20, 2006, in New Brighton, Pennsylvania, multiple cars released flammable liquid. For this accident, approximately 20 cars released an estimated 1,837,000 L [485,278 gal] of ethanol (National Transportation Safety Board, 2008). For the accident occurring on July 10, 2005, in Anding, Mississippi, there was a much smaller amount of flammable liquid released. In this accident, the locomotives released approximately 57,000 L [15,000 gal] of diesel fuel (National Transportation Safety Board, 2005) as a result of a head-on collision.

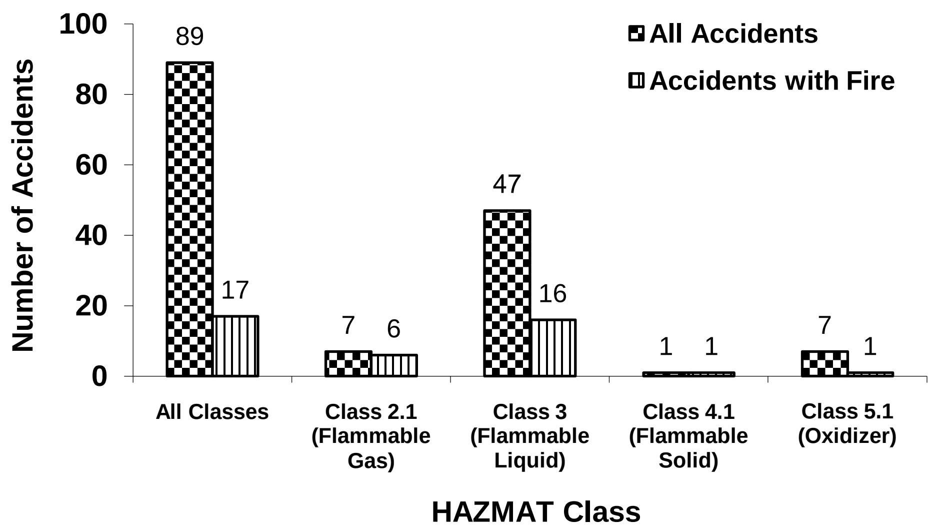


Figure 2-6. Number of HAZMAT Release Accidents From 1997 to 2008 That Occurred on the Main Line Showing Four of the HAZMAT Classes Involved. In Some Accidents, the Release Involved Material From More Than One HAZMAT Class.

As shown in Figure 2-6, Class 2.1 HAZMAT was released in seven accidents, and a fire resulted in six out of the seven accidents from 1997 to 2008 on the main line. As shown in Table 2-3, in all six accidents that resulted in a fire, flammable gas was released with flammable liquid. The one accident that did not result in a fire occurred on May 27, 2002, in Potterville, Michigan. In this accident, two cars released a combined total of about 26,000 L [7,000 gal] of liquefied petroleum gas (LPG). Other HAZMAT released in addition to the Class 2.1 HAZMAT was not identified from the database.

Figure 2-6 shows seven accidents in which Class 5.1 HAZMAT (i.e., oxidizer) was released from 1997 to 2008 on the main line. The one accident that resulted in a fire occurred on October 25, 2003, in Shorters, Alabama. For this accident, a combined total of approximately 216,000 L [57,171 gal] of flammable liquid was released in addition to approximately 1,134 kg [2,500 lb] of ammonium nitrate, an oxidizer. For the remaining six accidents, a release of flammable liquid, gas, or solid in addition to the release of oxidizer was not identified from the database.

2.4.3 Type of Accident

The majority (i.e., 85 out of 89) of the multiple-car HAZMAT release accidents occurring on the main line involved a derailment (Appendix A, Table A–1). However, four accidents involved an impact or collision. Three of these accidents resulted in a fire.

For the three impacts or collisions resulting in a fire, one of them was a head-on collision between two trains (i.e., July 10, 2005, in Anding, Mississippi), one involved the collision of a train with a backhoe that was left on the track by vandals (i.e., August 30, 2001, in Mulvane, Kansas), and one involved a side collision where a train struck the lead engine of another one that was standing (i.e., June 26, 1998, in Niota, Illinois). All three accidents involved the release of Class 3 HAZMAT. Approximately 57,000 L [15,000 gal] of diesel fuel were released in the head-on collision, and approximately 27,000 L [7,176 gal] of alcohol were released from perfume products in the collision with the backhoe.

In the side collision, some of the flammable liquid released was identified from the database but not all of it. In this accident, fewer than 380 L [100 gal] of flammable liquid was identified.

2.4.4 Yard, Industry, and Siding Accidents

In Figure 2-7, 30 accidents occurred off the main line and 3 of them resulted in a fire. Seventy percent of these accidents (21 out of 30) occurred in a rail yard with the remaining occurrences divided about equally among industry locations and rail sidings.

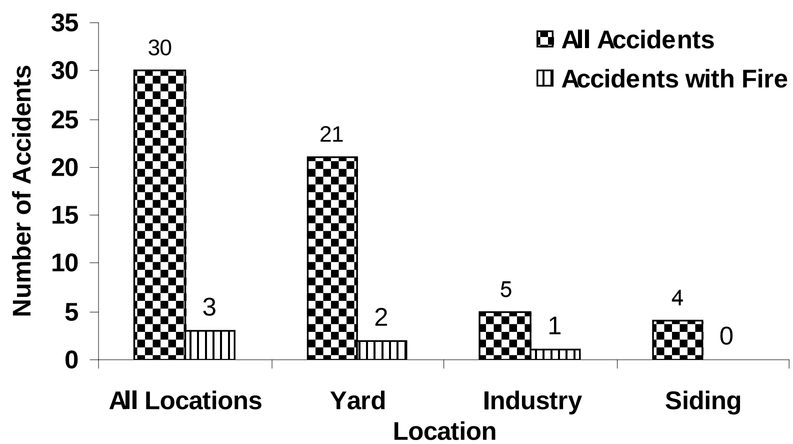


Figure 2-7. Summary of HAZMAT Release Accidents From 1997 to 2008 That Occurred Off the Main Line

As shown in Table 2-3, for the three accidents resulting in a fire, all three of them occurred in the last 5 years (i.e., 2004 to 2008). Two of them occurred in a rail yard, and one of them occurred at an industrial location. In addition, two accidents involved a derailment, while the remaining one involved an impact.

All three accidents resulting in a fire involved the release of Class 3 HAZMAT. Appendix B, Table B–1 shows the amount of HAZMAT released, as determined from the FRA and PHMSA databases. For the accident occurring on September 21, 2004, in East Saint Louis, Illinois, two cars released a combined total of more than 151,000 L [40,000 gal] of vinyl acetate at a rail yard from the impact of a 20-car train with a stopped car containing vinyl acetate (National Transportation Safety Board, 2005). Considerably less flammable liquid was released in the remaining two accidents. For the accident occurring on January 8, 2005, in Seabrook, Texas, 4,500 L [1,200 gal] of diesel fuel were released along with 380 L [100 gal] of hydrogen peroxide, an oxidizer. For the accident occurring on October 22, 2007, in Middlebury, Vermont, 1,900 L [500 gal] of gasoline were released.

2.4.5 Track Class

Figure 2-8 shows the multiple-car HAZMAT release accidents that occurred from 1997 to 2008 on the main line separated by track class. As shown in this figure, of the 89 accidents occurring on the main line, approximately 43 percent of them (i.e., 38 out of 89) occurred on Class 4 track. Assuming none of the 8 undetermined accidents resulted in a fire, then almost half of the accidents (i.e., 8 out of 17) involving a fire occurred on Class 4 track. The remaining accidents involving a fire were divided evenly among Class 2, Class 3, and Class 5 track. Three accidents occurred on each of these three classes of track.

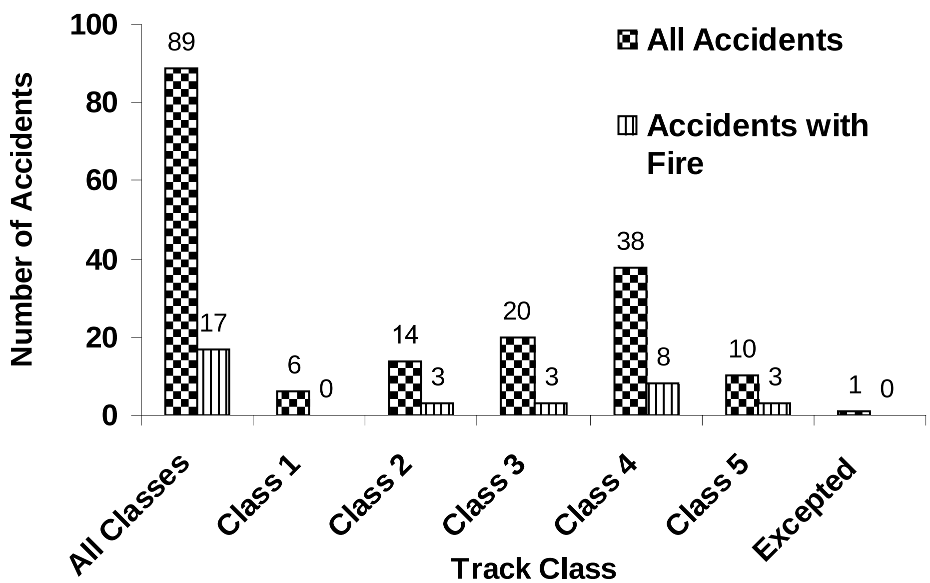


Figure 2-8. Number of Multiple-Car HAZMAT Release Accidents From 1997 to 2008 That Occurred on the Main Line Separated by Track Class

The maximum freight train speed increases with increasing track class, as shown in Table 2-4 (Federal Railroad Administration, 2003). Additionally required inspection frequencies vary by class of track; Classes 4 and 5 track have twice-weekly inspections, and excepted track and Classes 1, 2, and 3 track generally have a lower required inspection frequency as described in 49 CFR 213.233. Figure 2-8 shows the number of multiple-car HAZMAT release accidents increased from Class 1 to Class 4 track but then decreased for Class 5 track.

Table 2-4. Maximum Speed for Freight Trains by Track Class*

Track Class	Maximum Speed (mph)†
1	10
2	25
3	40
4	60
5	80
X (Excepted)	10

*Federal Railroad Administration. "FRA Guide for Preparing Accident/Incident Reports." DOT/FRA/RRS-22. Washington, DC: Federal Railroad Administration, Office of Safety. 2003.
†To convert to km/h multiply by 1.609.

Figure 2-9 shows the average number of cars that derailed and separates this average by track class. As shown in this figure, for the 89 accidents occurring on the main line from 1997 to 2008, on average, 19 cars derailed per accident for all classes of track. For the 17 accidents involving a fire, on average, 20 cars derailed per accident for all classes of track. The average was higher for Class 4 track: on average, 23 cars derailed in 38 accidents on this track (i.e., 21 percent increase), and 26 cars derailed in 8 accidents involving a fire on this track (i.e., 30 percent increase).

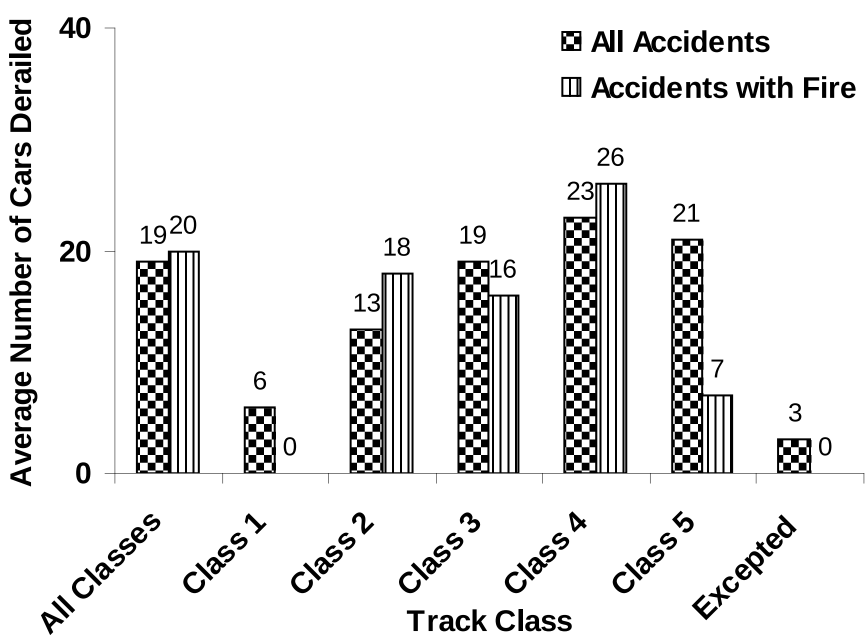


Figure 2-9. Average Number of Cars Derailed in Multiple-Car HAZMAT Release Accidents From 1997 to 2008 That Occurred on the Main Line Separated by Track Class

Figure 2-10 shows the average number of cars that released HAZMAT and separates this average by track class. As shown in this figure, for the 89 multiple-car HAZMAT release accidents, on average, 4 HAZMAT cars released HAZMAT per accident for all classes of track. This average is higher for the 17 accidents involving a fire. For these accidents, on average, six cars released HAZMAT for all classes of track, and for Class 3 or 4 track on average, seven cars released HAZMAT. For Class 3 or 4 track, the average number of HAZMAT cars releasing was 75 percent higher for accidents involving a fire compared to all of the multiple-car HAZMAT release accidents on Class 3 or 4 track. These values are influenced by the accident that occurred in New Brighton, Pennsylvania, where the train was on Class 4 track and 20 cars released HAZMAT, and the accident in Eunice, Louisiana, where the train was on Class 3 track and 18 cars released HAZMAT.

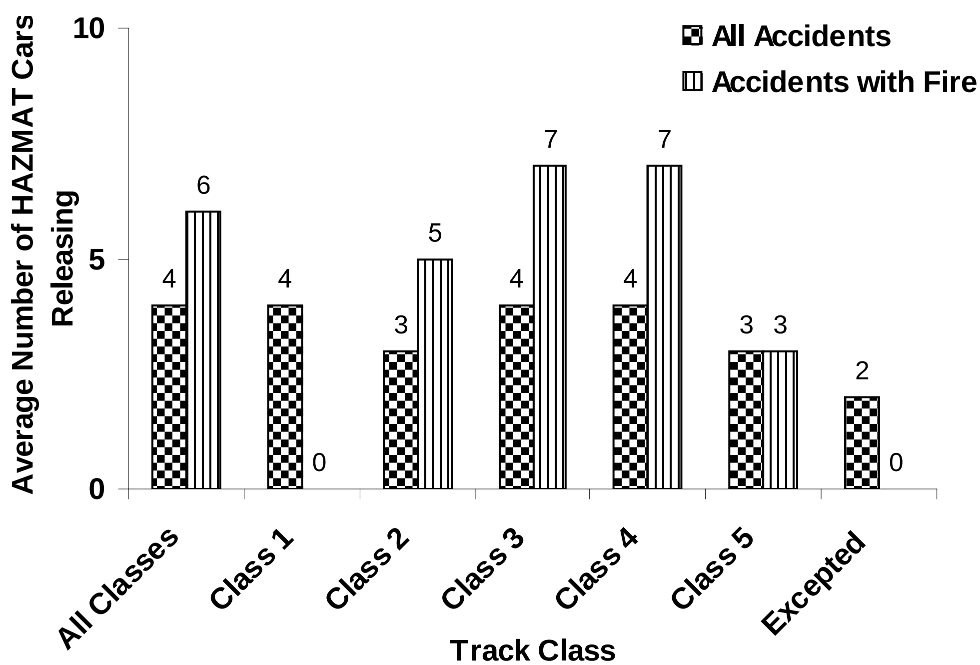


Figure 2-10. Average Number of HAZMAT Cars Releasing in Multiple-Car HAZMAT Release Accidents From 1997 to 2008 That Occurred on the Main Line Separated by Track Class

2.4.6 Train Speed

Figure 2-11 shows the multiple-car HAZMAT release accidents that occurred from 1997 to 2008 on the main line separated by train speed. In this figure, speed was arbitrarily separated into 32 km/h [20 mph] bins with the highest speed for the last bin corresponding to the maximum freight train speed for Class 5 track (Table 2-4). As shown in Figure 2-10, for the 89 accidents occurring on the main line, approximately 40 percent of them (i.e., 36 out of 89) occurred between 34 and 64 km/h [21 and 40 mph], with approximately 31 percent of them (i.e., 28 out of 89) occurring at higher speeds between 66 and 97 km/h [41 and 60 mph]. For accidents involving a fire, however, a greater percentage of the accidents occurred in the higher speed range {i.e., 66 to 97 km/h [41 to 60 mph]}. Almost half of them (i.e., 8 out of 17) occurred from 66 to 97 km/h [41 to 60 mph], whereas only 35 percent of them (i.e., 6 out of 17) occurred in the lower speed range of 34 to 64 km/h [21 to 40 mph].

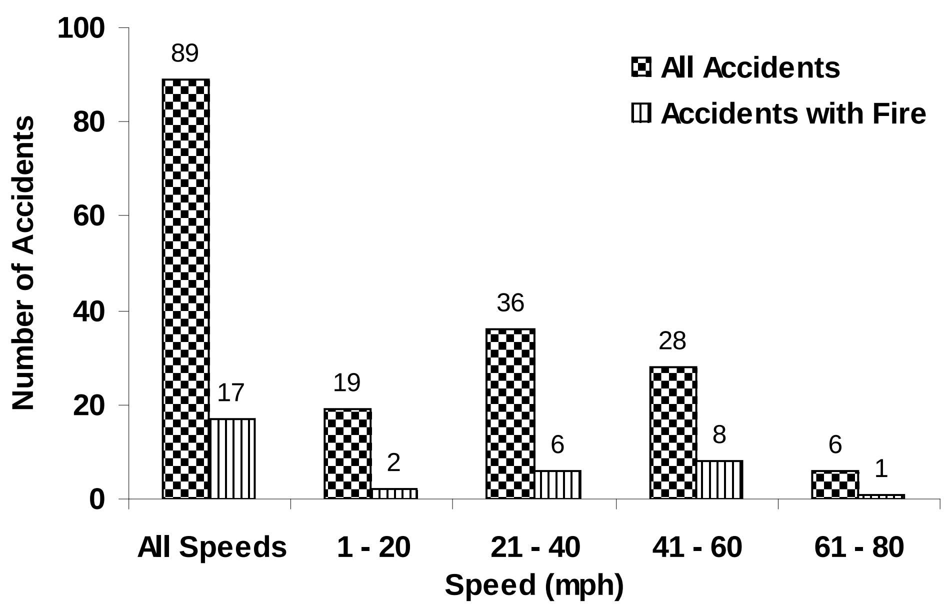


Figure 2-11. Number of Multiple-Car HAZMAT Release Accidents From 1997 to 2008 That Occurred on the Main Line Separated by Speed. To Convert Speed to km/h Multiply by 1.609.

Figure 2-12 shows the average number of cars that derailed and separates this average by train speed. As shown in this figure, for the 89 accidents that occurred on the main line from 1997 to 2008, on average, 19 cars derailed per accident over all speeds. For accidents involving a fire, on average, 20 cars derailed per accident over all speeds. Also, as shown in this figure, for the lower three speed ranges {i.e., speeds of 97 km/h or less [60 mph or less]}, the average number of cars that derailed per accident increases as train speed increases. However, in the range from 98 to 129 km/h [61 to 80 mph], the result is different. In this range, one accident occurred where only four cars derailed and it involved a fire. This accident occurred on September 2, 1998, in Crisfield, Kansas, and involved a train having 20 articulated cars with 3 to 5 platforms per car (National Transportation Safety Board, 2000). The accident may be underrepresented in Figure 2-11 because the four cars identified in the database did not capture the number of platforms that were also part of the derailment. In this case, each car contained multiple platforms and each platform may contain more than one cargo container as shown in Figure 2-13. In this accident, 12 cargo containers contained HAZMAT, 8 were involved in the derailment, and 4 were destroyed by fire (National Transportation Safety Board, 2000).

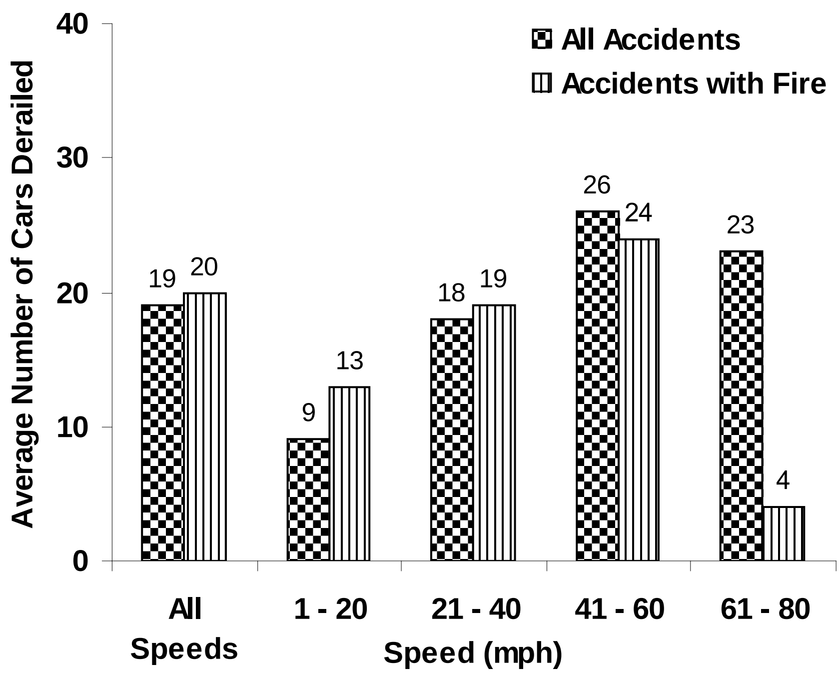


Figure 2-12. Average Number of Cars Derailed in Multiple-Car HAZMAT Release Accidents From 1997 to 2008 That Occurred on the Main Line Separated by Speed. To Convert Speed to km/h, Multiply by 1.609.

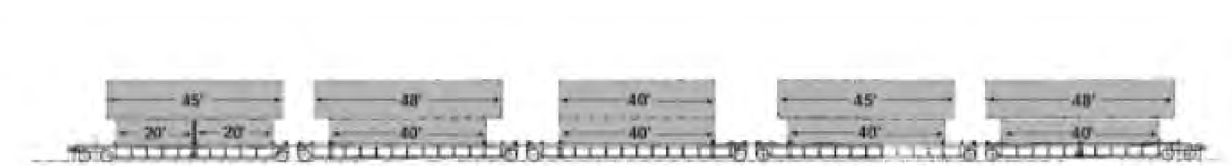


Figure 2-13. Car Having Multiple Platforms Carrying Containers Stacked Two High. This Image is From National Transportation Safety Board RAR-00/01.

Figure 2-14 shows the average number of cars that released HAZMAT and separates this average by train speed. As shown in this figure, for the 89 accidents that occurred on the main line, on average, 4 cars released HAZMAT over all speeds, and for the 17 accidents involving a fire, on average, 6 cars released HAZMAT over all speeds. When considering the individual speed ranges for all of the accidents (i.e., the 89 accidents occurring on the main line), 3 to 4 cars, on average, released HAZMAT per accident. However, for accidents involving a fire, the average was higher for the lower three speed ranges. In the range of 34 to 64 km/h [21 to 40 mph], on average, nine cars released HAZMAT. As shown in Figure 2-11, in this range, the average is based on six accidents. It includes the accident in New Brighton, Pennsylvania, where 20 cars released HAZMAT and the accident in Eunice, Louisiana, where 18 cars released HAZMAT. To either side of this range {i.e., 2 to 32 km/h and 66 to 97 km/h [1 to 20 mph and 41 to 60 mph]}, on average, five cars released HAZMAT.

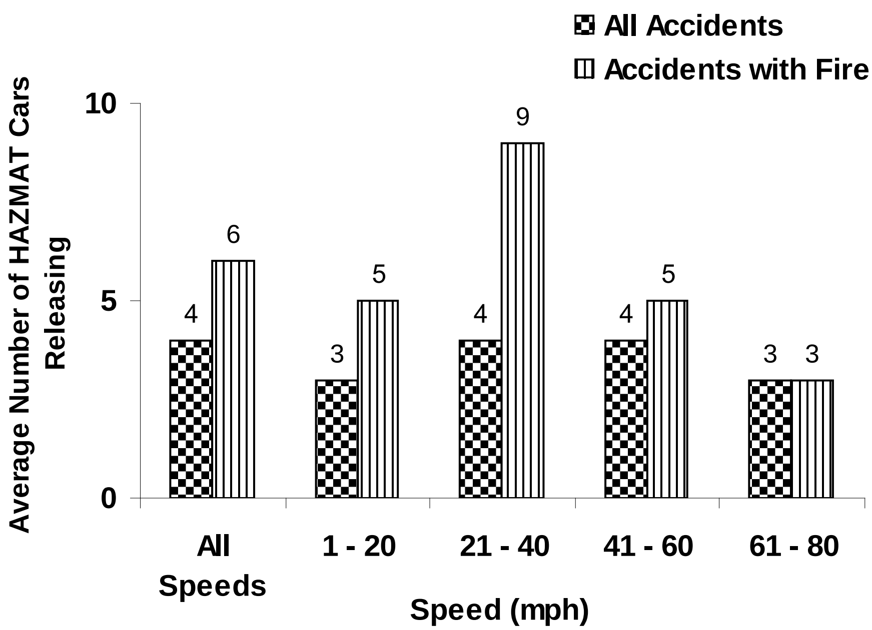


Figure 2-14. Average Number of HAZMAT Cars Releasing in Multiple-Car HAZMAT Release Accidents From 1997 to 2008 That Occurred on the Main Line Separated by Speed. To Convert Speed to km/h, Multiply by 1.609.

3 IDENTIFICATION OF SEVERE FIRE EVENTS

Following the review and categorization of the data described in the previous section, the next step is to identify the railway fires that had the greatest potential to create a fire environment for an SNF transportation package similar to the one established in NRC regulations. The regulations in 10 CFR 71.73(4) require an SNF transportation cask to survive a fully engulfing fire for a period of 30 minutes. When evaluating real-world historic railway accidents, a quantitative identification of a fully engulfing fire, as described in 10 CFR 71.73(4), can present some difficulties. Accident data are often in summary form, and records of exact fire durations, temperatures, and magnitudes for individual railcars were not generally found (as discussed next), making the absolute characterization of a fire as fully engulfing challenging.

In lieu of a quantitative identification of fully engulfing fires (which is not reasonably possible), this report identifies historic railway fires that had a reasonable potential to approach a fully engulfing fire similar to what is described in 10 CFR 71.73(4). These fires are herein referred to as “severe fires.” In this analysis, two criteria were used to define severe fires. The first criterion was that a railcar must have been substantially engulfed in a fire that persists for an extended period of time. The second criterion was that the principal source of fuel for the substantially engulfing fire must have been derived from another railcar. The purpose of this second criterion was to restrict the term “severe fires” to those fires that could have affected SNF transport packages (implicitly assuming SNF packages and their conveyances do not provide fuel to a fire) and exclude railcar fires that were self-fueled. Thus, under the constraints of this definition, a railcar affected by a severe fire is a railcar that was substantially engulfed in a sustained fire but did not provide the principal source of fuel to the fire.

These criteria defining severe fires contain some subjective elements—criterion one: “substantially engulfed” and “extended period of time” and criterion two: “principal source of fuel.” These subjective elements are a result of the often ambiguous information or descriptions provided in many accident reports. Often, the National Transportation Safety Board (NTSB) and the FRA accident reports are focused on identifying causes and deriving preventative measures rather than describing accident consequences. As a result, reports often provide very little specific information about ensuing fires. Damages are assessed in terms of lost equipment (fire damage and mechanical damage), length of damaged rail, and loss of lading (monetary impact of the event). Additionally, emergency response times are often presented in terms of times required to evacuate affected areas (secure public safety) and then declare areas safe for reentry. Without detailed descriptions, these assessments often relied on the interpretation of sparse information and details contained in accident photographs. These photographs provided information about a fire, either by recording the fire while active or by recording the extent of railcar damage after the fire had been extinguished. These photographs in conjunction with detailed descriptions (when available) also provided information about railcar configurations, which was a key element of the severe fire assessments. Because these accident images provide only snapshots of the events, there is the potential that evaluation of an event could be skewed by the timing or angle of a particular photograph. Care was taken to assess all of the information available for a given accident before making a determination on the severity of the fire involved with that accident.

As a consequence, using railway accident reports as a basis to classify railway fires often required the use of inferences rather than strict descriptions, and these inferences could have the potential for being interpreted subjectively. A general guideline for this analysis follows:

- “Substantially engulfed” was interpreted as (i) a fire that optically engulfs (or could have optically engulfed) at least 30 percent or one-third of the surface area of a railcar or

(ii) damage from fire appeared to have affected at least 30 percent or one-third of the surface area of a railcar.

- “Extended period of time” was interpreted as a duration that appeared to have lasted at least 30 minutes or that was documented as lasting longer than 30 minutes.
- “Non-self-fueled” was interpreted as a fire that was likely, at some point in time, fueled by materials from another railcar. This point arose from an occasional ambiguity in determining whether the contents of a railcar spawned a secondary fire as a result of a large initiating fire or whether the contents were the initial source of a fire.

Note that this analysis of severe fires does not address the railway configuration (separation) requirements in the DOT regulations (49 CFR 174.85) for HAZMAT rail shipments.

3.1 Railway Accidents Involved in Potential Severe Fires

On average, during the last 12 years (i.e., 1997 to 2008) more than 1,600 reportable freight train accidents occurred each year (Table 2-2), and of the total number of accidents, only a few were identified as having potentially severe fires. The process of identifying those accidents with severe fires began by identifying and focusing attention on accidents that involved the release of HAZMAT from multiple railcars and thus were potentially capable of supporting a severe fire. As described in Section 2.4, this reduced the number of candidate accidents to just 119 accidents that potentially had a sufficient amount of fuel to support a severe fire. Of these 119 accidents, just 20 involved a fire.

The purpose of this section is to (i) identify those events that involved severe fires and (ii) identify trends that could help identify severe fire accidents. The results of this section can then be used to (i) focus attention on those historic events that could have potentially approached (or exceeded) the regulatory hypothetical accident condition fire for shipping SNF packages and (ii) to identify any trends in these accidents that could be used to better understand the risks involved in transport of SNF by rail.

The 20 railway accidents identified as having the potential for a severe fire were initially identified through a search of the FRA database of railway accidents reported for the 12-year span from 1997 to 2008. These were accidents that involved a fire and the release of HAZMAT from multiple railcars. After these accidents were identified, details about these accidents were then derived from available NTSB reports and Rail Accident Briefs (RAB). However, of the 20 accidents initially identified, reports were not found for several accidents. These missing reports were either pending for recent accidents or simply not available through the NTSB electronic publications portal for railroad accidents. Consequently, these events were not evaluated to determine fire severity, nor were they included in the severe accident parameter trend analysis in Section 3.3. These excluded railway accidents were

- Luther, Oklahoma, August 22, 2008: FRA/PHMSA database reports five cars releasing Class 3 materials (FRA report pending HQ–2008–70) http://www.koco.com/video/17271337/index.html
- Caney, Oklahoma, October 23, 2008: FRA/PHMSA database reports three cars releasing Classes 2 and 3 materials (FRA report pending HQ–2008–81)
- Nolan, North Dakota, December 7, 2008: FRA/PHMSA database reports six cars releasing Classes 2 and 3 materials (FRA report pending HQ–2008–92) http://www.youtube.com/watch?v=1S9txPvUTF8

- Middlebury, Vermont, October 22, 2007: FRA/PHMSA database reports four cars releasing Class 3 materials; no report found
- Shorters, Alabama, October 25, 2003: FRA/PHMSA database reports three cars releasing Classes 3 and 5.1 materials; no report found
- Mulvane, Kansas, August 30, 2001: FRA/PHMSA database reports three cars releasing Classes 3 and 9 materials, no report found. http://lubbockonline.com/stories/083001/upd_075-6252.shtml
- Plymouth, Minnesota, December 18, 2000: FRA database reports six cars releasing Class 4 materials; no report found
- Niota, Illinois, June 26, 1998: collision, FRA reports four cars releasing Class 3 and corrosive materials; no report found

Of the 20 initially identified accidents, accident reports were found for 12. A preliminary examination of these accidents was used to separate accidents according to the type of rail line on which they occurred, either main line or yard line.

The main line accidents initially identified were

- New Florence, Pennsylvania, December 28, 2009, derailment: FRA reports two cars releasing Class 3 materials; FRA Office of Safety Headquarters Assigned Accident Investigation Report HQ–2007–85
- Painesville, Ohio, October 10, 2007, derailment: FRA reports five cars releasing Class 3 and miscellaneous materials; NTSB/RAB–09/02
- Oneida, New York, March 12, 2007, derailment: FRA reports six cars releasing Classes 2 and 3 and corrosive materials; NTSB/RAB–08/05
- Brooks, Kentucky, January 16, 2007, derailment: FRA reports seven cars releasing Classes 2 and 3 and corrosive and miscellaneous materials; FRA Office of Safety Headquarters Assigned Accident Investigation Report HQ–2007–03
- New Brighton, Pennsylvania, October 20, 2006, derailment: FRA reports 20 cars releasing Class 3 materials; NTSB/RAR–08/02
- Anding, Mississippi, July 10, 2005; collision: FRA reports two cars releasing Classes 2 and Class 3 materials; NTSB/RAR–07/01
- Tamaroa, Illinois, February 9, 2003; derailment: FRA reports seven cars releasing Classes 2 and 3 and miscellaneous materials; NTSB/RAR–05/01
- Baltimore, Maryland, July 18, 2001; derailment: FRA reports four cars releasing Class 3 and miscellaneous materials; RAB–04/08
- Eunice, Louisiana, May 27, 2000; derailment: FRA reports 18 cars releasing Classes 2, 3, and 6 and corrosive materials; RAR–02/03
- Crisfield, Kansas, September 2, 1998, derailment: FRA reports three cars releasing Class 3; materials; RAR–00/01

The yard line accidents were

- Seabrook, Texas, January 8, 2005, derailment: FRA reports two cars releasing Class 5 materials (and Class 3 from the locomotive); FRA Office of Safety Headquarters Assigned Accident Investigation Report HQ–2005–05

- East St. Louis, Illinois, September 21, 2004, derailment: FRA reports two cars releasing Class 3 materials; RAB–05/04

In addition to those accidents that involved fires and the release of HAZMAT from at least two railcars, three accidents were further examined.

- Texarkana, Arkansas, October 15, 2005, RAB–06/04
- Momence, Illinois, March 23, 1999, RAB–02/02
- Delia, Kansas, July 2, 1997, RAR–99/04

These three accidents were examined because of several noteworthy issues. The Texarkana accident demonstrated how flammable material released from a railcar may potentially affect railcars on adjacent tracks, when railcars are in rail yards. The Momence accident demonstrated how fires involving only fuel released from locomotives could potentially affect railcars. And the Delia accident was noteworthy because the fire in this accident resulted in the release of a small amount of radioactive materials (not from an SNF package).

3.2 Brief Description of Railway Accidents

A brief description of the evaluated accidents is provided in the next section. These accidents have been grouped according to the occurrence of severe fires. The first set contains those accidents for which no severe fires were identified. The second set are those for which widespread severe fires were identified, and the last set are those for which localized severe fires were identified.

3.2.1 Accidents With No Severe Fire

After examining the accidents previously listed in Section 3.1, several of the accidents were determined not to have had severe fires. These accidents are described next.

New Florence, Pennsylvania, December 28, 2007

On December 28, 2007, near New Florence, Pennsylvania, a fire occurred as a consequence of a derailment; 9 railcars derailed from a three-locomotive, 41-car train traveling at 37 km/h [23 mph]. Of the nine derailed railcars, seven were transporting hazardous flammable liquids and one was transporting LPG. Two of the railcars transporting hazardous flammable liquid leaked and caught fire. Liquid loss from one railcar was estimated as minimal, while the second railcar was estimated to have lost approximately 57,000 L [15,000 gal]. Figure 3-1 shows the positions of the derailed railcars and annotates those railcars that were affected by fire. Evident in this figure is the nearly linear arrangement of the derailed railcars, which makes it difficult for railcars to be affected by fuel or fire from adjacent railcars. This nearly linear arrangement of the derailed railcars and a relatively limited supply of fuel prevented this accident from producing a severe fire. The sparse arrangement of railcars maximized the distance between the fire and any potentially affected railcars, and the limited amount of fuel produced a fire with a minimal radius of effect.[1]

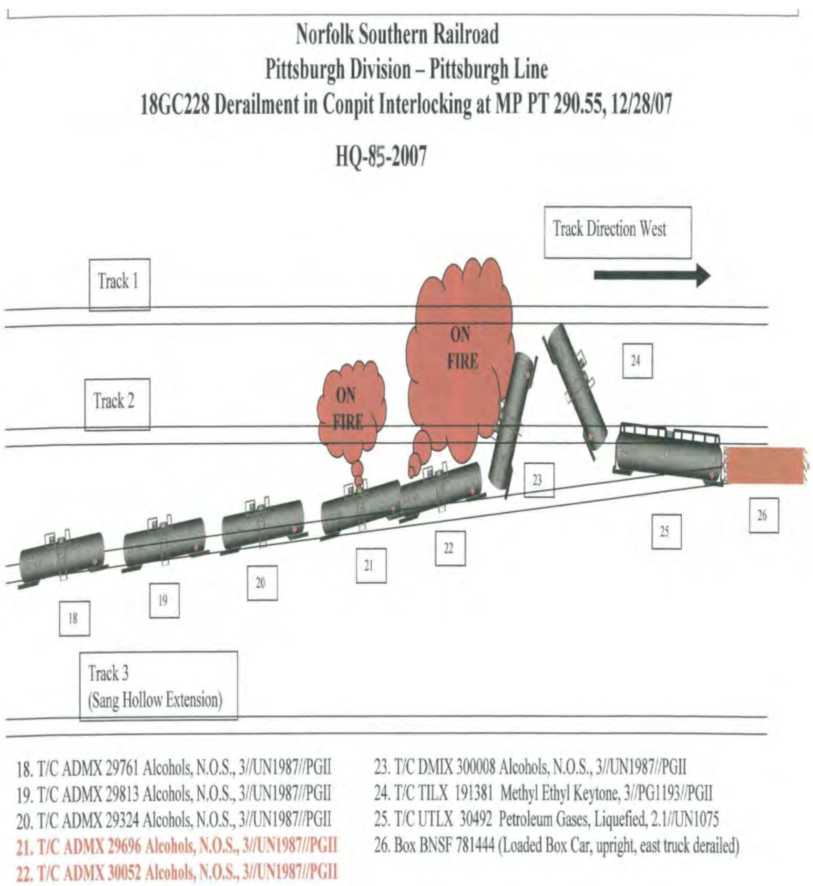


Figure 3-1. Diagram of Railway Accident Near New Florence, Pennsylvania. This Figure Depicts Nine Derailed Cars, Two of Which Were Damaged by Fire. This Accident Illustrates the Concept of Nearly Linear Railway Accidents. Figure From FRA Office of Safety Headquarters Assigned Accident Investigation Report HQ–2007–85.

[1]Because of a limited amount of fuel, it was unlikely that the fuel could flow to an adjacent railcar in sufficient quantity to fully engulf it.

Seabrook, Texas, January 8, 2005

On January 8, 2005, in a rail yard near Seabrook, Texas, a Union Pacific train derailed 1 locomotive and 3 of its 50 railcars while traveling at 8 km/h [5 mph]. Diesel fuel from the damaged locomotive and HAZMAT from the three derailed cars were released as a consequence of the derailment. The HAZMAT released from these cars was nonflammable, but it was an oxidizer. The fire fueled by spilled diesel from the damaged locomotive was extinguished immediately upon arrival of emergency response services.

The derailed cars in this accident were arranged in a sequential linear fashion along the side of the rail line. The sparse arrangement of railcars maximized the distance between a fire and any potentially affected railcars, and the limited amount of fuel produced a fire with a minimal radius of effect. In addition, the fire that resulted from this accident was quickly suppressed by first responders. This quick fire suppression is presented as further evidence that this was not a significant or potentially severe fire. Based on a review of the accidents evaluated in this analysis, it appears that significant fires are rarely quickly suppressed.

Note that significant fires appear to present a variety of challenges for emergency responders that prevents the fires' immediate suppression. These challenges include addressing the magnitude and scope of the fire, the large uncertainty in the composition and possible progression of a large fire, the potential release of additional fuel or HAZMAT, and the associated hazards to the firefighters and the public, as well as the logistics of suppressing a large fire. For these reasons, it is assumed that if a fire was quickly suppressed, it was likely a relatively small and inconsequential fire.

Crisfield, Kansas, September 2, 1998

On September 2, 1998, the 17^{th} through the 19^{th} cars and the first two platforms of the five-platform 20^{th} car of a Burlington Northern and Santa Fe Railway Company intermodal freight train derailed near Crisfield, Kansas, while traveling at 109 km/h [68 mph]. From the description in National Transportation Safety Board (2000), this accident appeared to result in a sparse distribution, with insufficient fuel to produce a severe fire.

3.2.2 Accidents With Widespread Railcar Severe Fires

Among the accidents identified as having a potential for severe fire, several accidents were categorized as accidents in which severe fires could have affected numerous railcars. Descriptions of these accidents follow.

New Brighton, Pennsylvania, October 20, 2006

On October 20, 2006, in New Brighton, Pennsylvania, a derailment occurred on the Beaver River railroad bridge. The train was transporting 86 railcars, 83 loaded with denatured ethanol and 3 empty (likely a unit train, but not specified). The train was traveling at 60 km/h [37 mph], and as it crossed a bridge, a rail failure occurred, resulting in 23 railcars derailing (railcars 23 through 45). Of the 23 derailed cars, 20 released flammable liquids, which ignited and subsequently burned for about 48 hours. An aerial photograph from the accident is shown in Figure 3-2.

Figure 3-2. Photograph of Derailment, New Brighton, Pennsylvania, October 20, 2006. This Image is From National Transportation Safety Board RAR–08/02.

Interpretations of the accident report and photographs were used in this analysis. Of the 23 cars derailed, the configuration of the derailed cars can be separated into essentially two groups: those that remained on grade with the rail line (of which 6 maintained a sparse linear arrangement and 4 collapsed in an accordion arrangement) and 13 cars that landed below grade on the bank of the river bed (of which 3 were isolated and partially submerged and 10 were entangled in a disorganized heap on the bridge embankment). Based on the arrangement of the railcars, the fuel available, and the total duration of the fire and the appearance of fire damage to the railcars, it is estimated that 14 railcars (i.e., 10 cars in the embankment heap and 4 cars in the accordion arrangement) could have met criterion one of a severe fire (extended duration, significantly engulfing fire). However, because almost every derailed car carried flammable liquids, it is unclear how the fire proceeded and which cars were damaged as a consequence of self-fueled fires or from fire fueled from adjacent cars. Thus, as a conservative estimate, as many as 14 railcars could be evaluated as having been affected by fires from adjacent railcars. And, as a consequence of this conservative estimate, 14 railcars can be conservatively estimated as exposed to a severe fire. However, based on observations made during the review of all the railway accidents in this assessment (see Section 3.1), it is reasonable to assume that a large fraction of the railcars was damaged during the impact of this substantial derailment and that these damaged railcars released flammable liquids, resulting in several self-fueled railcar fires. Thus, based on these observations, a more likely estimate for the number of railcars affected by severe fire is three to five.

Eunice, Louisiana, May 27, 2000

On May 27, 2000, near Eunice Louisiana, a Union Pacific Railroad train derailed 33 of 113 railcars as a result of a rail misalignment over a small bridge. Of the derailed railcars, 15 contained HAZMAT including flammable liquids and gases. The release of flammable materials resulted in fires and explosions, which significantly affected a large fraction of the derailed cars. First responders were onsite within 7 minutes, and a containment zone was established within 3 hours. However, it required several days to safely contain this accident. An aerial photograph from the accident is provided in Figure 3-3.

Figure 3-3. Train Derailment Near Eunice, Louisiana, on May 27, 2000. This Image is From National Transportation Safety Board RAR–02/03.

A configuration of the accident was derived from descriptions, diagrams, and photos provided in the accident report and a diagram from the report is shown in Figure 3-4. Based on the configuration of the derailed cars, the cars can be separated into two groups: (i) those linearly arranged and on grade with the rail line and (ii) those below grade and strewn about in a loose heap. From the figures and details in the report, it was determined that the nine cars linearly aligned on grade (two not shown in diagram) were not damaged by fire and therefore were not affected by severe fires. Those railcars that were significantly damaged by fire but appeared to have been self-fueled include (i) two railcars lying nearly perpendicular to the rail track on the leftmost portion of Figure 3-4, (ii) two cars in the creek bed, and (iii) three isolated railcars.

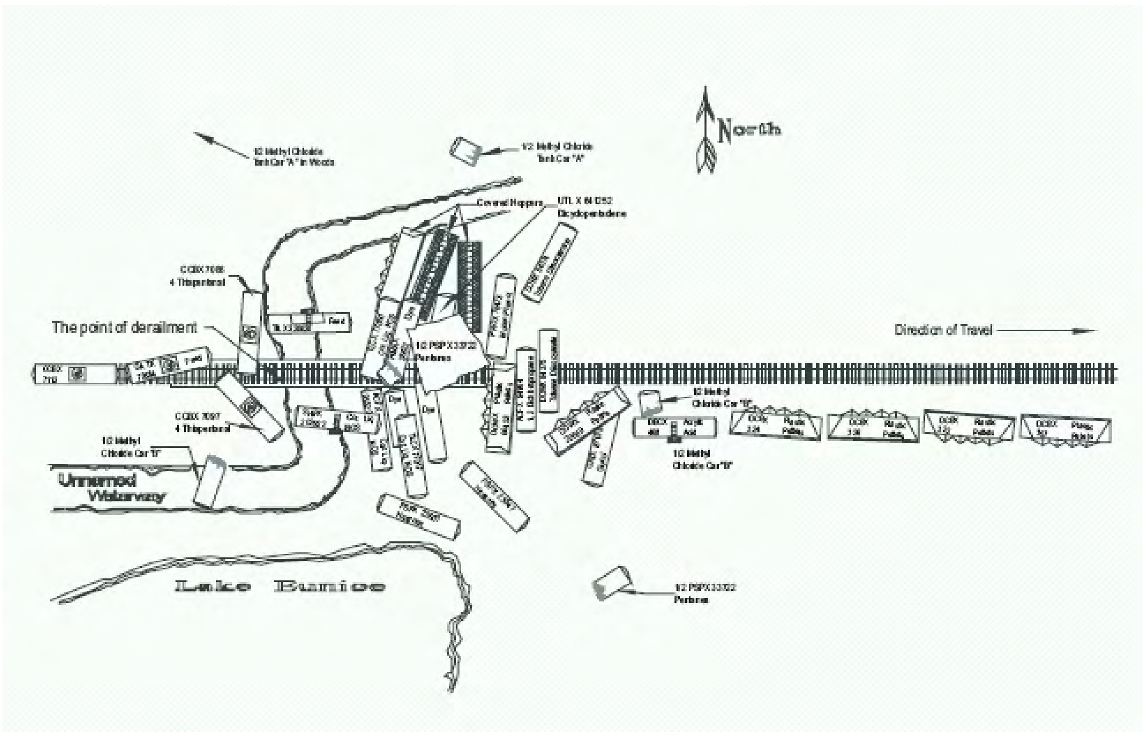


Figure 3-4. Diagram of the Derailment Near Eunice, Louisiana, on May 27, 2000. This Image is From National Transportation Safety Board RAR–02/03.

The remaining 17 cars meet criterion one of a severe fire, and because of the uncertainty in the progress of the fire and in whether the fire damage was the result of self-fueled fires, 17 railcars could be conservatively assumed to have been affected by severe fires. However, knowing that nearly half of the derailed cars contained flammable liquids and asserting that some of those released flammable liquids as a result of damage incurred during the derailment, it is likely that several self-fueled fires occurred. By accounting for these self-fueled fires, it is estimated that around 9 railcars were affected by severe fire.

Thus, based on this evaluation, it is conservatively estimated that as many as 17 railcars were affected by severe fires, but that a more likely number of railcars affected by severe fire is 9.

3.2.3 Accidents Involving Local Severe Fires

After examining railway accidents that had some potential for severe fires, the majority were determined to have had some railcars that were affected by severe fires. These local severe fire accidents follow.

Painesville, Ohio, October 10, 2007

On October 10, 2007, a CSX Transportation freight train derailed 31 of 106 railcars while traveling on a main line at 77 km/h [48 mph]. NTSB and FRA investigators determined the cause of this accident to be a rail failure. Of the derailed cars, seven were carrying ethanol, one was carrying LPG, and one was carrying phthalic anhydride, with the other cars transporting corn, wheat, feed, plastic, and lumber. As a consequence of the derailment, several of the cars carrying ethanol leaked and ignited, resulting in a fire that burned for 36 hours. A photograph of the aftermath of this accident is shown in Figure 3-5.

Figure 3-5. Photograph of Derailment Near Painesville, Ohio, on October 10, 2007. This Image is From National Transportation Safety Board RAB–09/02.

Based on information provided from the accident report and details from the photograph, the following was determined. About 9 of the 31 cars were arranged in a dense heap, in which several railcars were exposed to fire. The other 22 cars were arranged linearly along the track and were not involved in any fires. Of the nine cars in the heap, four cars appear to meet criterion one of a severe fire. Of these four cars, it was estimated using accident report data that two cars were affected by self-fueled fires. Therefore, it is estimated that only two railcars met both criteria for a severe fire. Thus, it was estimated that two railcars were affected by severe fires.

Oneida, New York, March 12, 2007

On March 12, 2007, near Oneida, New York, a CSX Transportation freight train derailed 29 of 78 railcars (cars 25 through 52) while traveling on a main line at 76 km/h [47 mph]. NTSB and FRA investigators determined the cause of this accident to be rail failure. Of the 29 cars derailed, 22 were tank cars loaded with HAZMAT. Of these, six tank cars were breached, including four transporting LPG, one transporting toluene, and one transporting ferric chloride acid (hazardous but not flammable). The release of materials resulted in fires and explosions.

The accident report does not provide any images or sketches; however, Figure 3-6 provides a photograph taken by a local paper.

Figure 3-6. Photograph of Derailment Near Oneida, New York, March 12, 2007 (Mike Greenlar, *Post-Standard* Staff Photographer, Used With Permission of the *Post-Standard*, ©Copyright 2007)

From the report it can be determined that the accident occurred on a straight rail with no grade, along a level terrain. The majority of the derailed cars were contained in a single heap of 27 cars, with 2 additional cars isolated by several hundred feet from any other car. Of the four LPG tanks ruptured, three were initially sequential cars (30, 31, and 32, as numbered from the front of the train) and the fourth LPG car was car 42; each of these ignited and burned until the LPG was completely consumed by the fire. The railcar carrying toluene was car 34, had about 1,900 L [500 gal] consumed by the fire. Note that this car was releasing material as a consequence of tank venting (i.e., a tank car had been exposed to elevated temperatures for a prolonged period).

The fire affecting railcar 42 (LPG) was entirely self-fueled, and no other railcars in the vicinity of that car were significantly affected by fire. This conclusion is based on the assumption that the railcars in the immediate vicinity of car 42 were tank cars, which if they had been exposed to prolonged elevated temperatures would have vented HAZMAT because of a pressure buildup caused by heat from a fire. Considering that 22 of the 27 derailed cars were tank cars, there is a high possibility that neighboring railcars would have been tank cars. And if HAZMAT had been released, the release would have been annotated in the accident report.

The fires affecting cars 30, 31, 32, and 34 are likely related based on their sequential arrangement. The occurrences of explosions and the venting of toluene from car 34 provide evidence that at least one of the three cars (30, 31, or 32) was initially damaged during the derailment, resulting in a self-fueled fire and subsequent fires. Conservatively, it is assumed that only one of the LPG cars in this group (30, 31, or 32) was initially damaged during the derailment and this fire caused subsequent fires. This assumption maximizes the estimated number of cars in this group (30, 31, 32, and 34) potentially affected by severe fires to three railcars. While the subsequent fires likely resulted in additional self-fueled fires, they are included as cars that were affected by severe fires.

The railcar releasing ferric chloride is not addressed by any specific information in the accident report. As a consequence, it is conservatively assumed to have released materials as a consequence of a severe fire.

Thus, based on this evaluation, it is conservatively estimated that as many as four railcars were affected by severe fires. No estimate is provided for a "likely" number of affected railcars because no obvious basis can be made to reasonably constrict the conservative estimate.

Brooks, Kentucky, January 16, 2007

On January 16, 2007, 26 railcars derailed from an 80-car CSX Transportation freight train (cars 15 through 40) while traveling on a main line at 76 km/h [47 mph]. NTSB and FRA investigators determined the cause of the derailment to be a failure of a railcar truck. Photographs of the derailment are shown in Figures 3-7 and 3-8.

Figure 3-7. Photograph of Brooks, Kentucky Derailment, January 16, 2007 (Michael Clevenger, *The Courier-Journal* Staff Photographer, Used With Permission of *The Courier-Journal*, ©*The Courier-Journal,* 2007)

Of the 26 derailed cars, 12 were tank cars carrying HAZMAT and 5 were empty. Seven of the tank cars were punctured or breached, releasing hazardous liquids as a result of damage from the derailment. Four of these damaged tank cars released flammable materials (three liquid, one gas) that ignited and burned.

Figure 3-8. Photograph of a Train Derailment in Brooks, Kentucky, on January 16, 2007. This Image Depicts a Loosely Organized, Accordion-Type Heap of Railcars, With Railcars Linearly Arranged on the Periphery of the Heap. This Image Is From Regional Response Team Region IV http://www.nrt.org/Production/NRT/RRTHome.nsf/resources/RRTIVJanMeetings/$File/RRT%20Brooks.pdf.

The accident report provided sufficient information to identify the location of the railcars releasing flammable materials. Three of the four tank cars that released flammable materials were breached by the derailment, with the fourth car damaged and leaking. The breaches resulted in a complete release of the tank car contents and subsequent large engulfing fires. Two of these cars were located in the dense derailment heap. The third breached car and the fourth car releasing flammable materials were located aside the rail track, slightly isolated from the railcar heap.

Based on the configuration of the derailed cars and the locations of the fires, the following was determined: (i) the two fires associated with railcars not in the heap were sufficiently isolated to not have affected any adjacent railcars and (ii) the two fires associated with railcars in the heap were large engulfing fires, which had capacity to affect railcars in the immediate vicinity of the breached railcars. Because of the disordered arrangement of the railcars in the heap and because of the dense accordion arrangement of the heap, it is postulated that for each fire, two adjacent railcars could have met the criteria of a severe fire.

It is conservatively estimated that eight railcars met criterion one of a severe fire (four of which were self-fueled). It is also conservatively estimated that four railcars met both criteria and thus are categorized as severe fires.

Anding, Mississippi, July 10, 2005

On July 10, 2005, a train collision between Canadian National freight trains occurred near Anding, Mississippi. This collision occurred between northbound and southbound trains traveling on a main line rail. The northbound train was traveling at 72 km/h [45 mph], transporting 137 cars: 118 were empty, 11 were loaded (5 containing HAZMAT), and 8 contained chemical residues. The southbound train was traveling at 37 km/h [23 mph], transporting 107 cars: 52 were empty, 53 were loaded (15 containing HAZMAT), and 2 contained chemical residues. A photograph of a limited portion of the accident is shown in Figure 3-9.

Figure 3-9. Photograph of the Anding, Mississippi, Train Collision and Derailment. This Image is From National Transportation Safety Board RAR–07/01.

In this accident, 6 locomotives and 17 cars were derailed (8 on the northbound and 9 on the southbound trains). Damaged locomotives released 57,000 L [15,000 gal] of diesel fuel, which ignited and burned for about 12 hours. The resulting fire caused one or more residue cars to begin venting because of pressure buildup caused by the heat of the fire (National Transportation Safety Board, 2007). These residue cars, which were tank cars that contained trace or small amounts of material, were among the nine leading cars on the southbound train. They had been placed there as buffer cars by the train engineer and conductor to separate the locomotives from several tank cars carrying hydrogen cyanide (cars 10 through 13, which did not derail). No other information is provided about the configuration of railcars involved in this accident.

Based on the observation of venting from one or more of the residue cars (National Transportation Safety Board, 2007), it is assumed that one or two railcars had been substantially engulfed in prolonged duration fires, which were not self-fueled. Thus, it is estimated that two railcars were affected by severe fires in this accident.

Tamaroa, Illinois, February 9, 2003

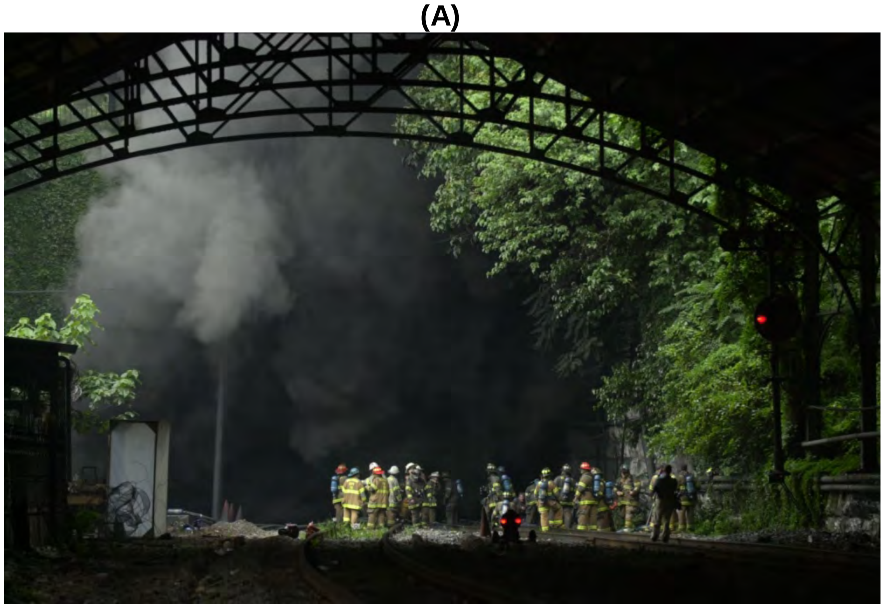
On February 9, 2003, a northbound Canadian National freight train, designated as a "key train," derailed 22 of 108 cars in Tamaroa, Illinois, while traveling at 64 km/h [40 mph] on a main line rail. This accident was caused by a rail failure. Of the 108 railcars being transported, 76 were loaded and 32 were empty. Of the derailed cars, four released methanol and the methanol from two of these four cars fueled a fire that burned for about 24 hours. Other HAZMAT, both flammable and nonflammable, was also released from damaged railcars, but these materials did not result in fires. A photograph of this accident is shown in Figure 3-10. This image depicts a tightly packed accordion arrangement of railcars in the derailment heap. No other information about railcar configuration or distribution was provided. The prolonged duration of the burning fires suggests that these fires were large and potentially engulfing. Because of the tight accordion arrangement of railcars, it is reasonable to assume that up to two railcars rested immediately adjacent to each of the railcars engulfed in large fires. Thus, based on these assessments, it is conservatively estimated that four railcars were affected by severe fires.

Figure 3-10. Photograph of the Derailment of a Canadian National Freight Train in Tamaroa, Illinois, on February 9, 2003. This Photograph Shows a Portion of the Railcar Heap Resulting From This Accident. The Arrangement of Railcars Illustrates the Concept of an Accordion Arrangement of Derailed Railcars. This Image Is From National Transportation Safety Board RAR–05/01.

Baltimore, Maryland, July 18, 2001

On July 18, 2001, a CSX freight train derailed 16 of 60 cars as it was passing through the Howard Street tunnel in Baltimore, Maryland. The derailment occurred at a speed of 29 km/h [18 mph] and was caused by a rail line misalignment. During the derailment, one railcar carrying a flammable liquid (tripropylene) was punctured. This material ignited, and a fire spread to the contents of several adjacent railcars carrying wood and paper products. In addition, two tank cars carrying hydrochloric acid were breached because of exposure to high temperatures, resulting in thermal degradation of the tank liners and corrosive penetration of one of the cars. Because the accident occurred within a tunnel, smoke and heat precluded access to the tunnel while the fire burned (see Figure 3-11).

(A)



(B)

Figure 3-11. Photos from the Baltimore Tunnel Fire July 18, 2001 [(A) Kim Hairston and (B) John Makely, *The Baltimore Sun* Media Group Staff Photographers, Reprinted With Permission of *The Baltimore Sun* Media Group, All Rights Reserved ©Copyright 2001]

The following assumptions were made when estimating the number of railcars affected by severe fires in this accident:

- The relatively slow speed of the accident and the confines of the tunnel likely resulted in a low density, nearly linear arrangement of derailed cars.
- The nearly linear arrangement of railcars limited the number of cars affected by the release of flammable liquids to those cars immediately preceding and following the leaking tank car.
- Damage to the tank cars carrying hydrochloric acid and wood and paper products is evidence that the fire was sufficient to affect neighboring railcars.

This railway accident was previously studied in detail in NUREG/CR–6886, “Spent Fuel Transportation Package Response to the Baltimore Tunnel Fire Scenario” (Adkins, et al., 2006). Based on report descriptions, it was determined that the railcars adjacent to the tank car, which released flammable material, were damaged as a result of exposure to thermal loading. Information in the accident report was used to determine that the damage adjacent railcars incurred was from a thermal load much smaller than that of a severe fire. However, because a clear distinction cannot be drawn based on the descriptions provided, it is conservatively estimated that both of the railcars adjacent to the tank car leaking flammable liquid met both the criteria of a severe fire. Thus, it is estimated that two railcars were potentially affected by severe fires.

East St. Louis, Illinois, September 21, 2004

On September 21, 2004, in the Gateway Hump Yard in East St. Louis, Illinois, an Alton and Southern Railway Company remote control train derailed. The train collided with a tank car containing vinyl acetate (flammable liquid); in the subsequent derailment, vinyl acetate, which leaked from two tank cars, caught fire. An additional three tank cars carrying ethylene glycol also derailed but did not leak or contribute to the fire. A diagram of the accident is shown in Figure 3-12. No further details were provided about the duration of the ensuing fire. Based on the annotation of a damaged railcar on an adjacent rail (Figure 3-12), it is conservatively assumed that this affected railcar was involved in a significantly engulfing fire. As a consequence, it is estimated that three railcars meet criteria one of a severe fire, while only the affected railcar on the adjacent track meets both criterion one and two. Thus, it is estimated that one railcar was affected by a severe fire in this accident.

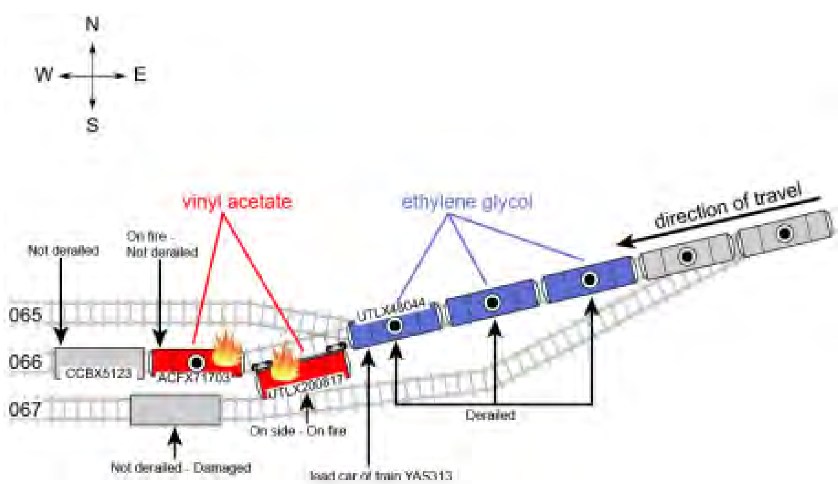


Figure 3-12. Diagram of Accident in East St. Louis, Illinois, Gateway Hump Yard. This Image Is From National Transportation Safety Board RAB–05/04.

3.2.4 Other Noteworthy Events

In addition to accidents that involve a fire and releases from multiple railcars, descriptions of three additional noteworthy incidents follow.

Texarkana, Arkansas, October 15, 2005

On October 15, 2005, in a rail yard in Texarkana, Arkansas, two Union Pacific trains collided (head to tail) at a speed of 27 km/h [17 mph]. Three cars derailed on the end of the tail-struck train, one of which was a tank car. On the other train, the 18th car derailed, causing the 17th and 19th cars to collide. The collision of the 17th and 19th cars resulted in a puncture in the end of the 19th car, which released a flammable pressurized gas, propylene. Flowing propylene gas reached a house and ignited, resulting in an explosion that destroyed the house and a second home. The fire rapidly burned back to the punctured car. Then, under the supervision of emergency responders, the fire was allowed to burn for an additional 12 hours. The fire destroyed the leaking tank car, damaged four cars on an adjacent track, and completely burned a railroad trestle. A photograph of this accident is provided in Figure 3-13.

Figure 3-13. Aerial Photograph of the Train Derailment and Fire in Texarkana, Arkansas, on October 15, 2005. The Widespread Fire Was the Result of Flowing Flammable Gas, Which Filled a Large Area Before Igniting in an Occupied House Along the Rail Line. This Image Is From National Transportation Safety Board RAB-06/04.

Based on this description, it is conservatively estimated that as many as four railcars were affected by severe fires (the four damaged railcars on the adjacent track). However, because the fuel was a gas, it is likely that the fire burned back to the vicinity of the leaking tank car, and that only one railcar on the adjacent track would have likely met the criteria of significantly engulfing fire, while the remaining three railcars were affected by minor secondary fires. It was likely that only one railcar was affected by a severe fire.

Momence, Illinois, March 23, 1999

On March, 23, 1999, an eastbound Consolidated Rail Corporation train struck the side of the lead locomotive on a southbound Union Pacific train at a rail crossing. This collision resulted in the derailment of the locomotives and the first 16 railcars on the southbound train and the lead locomotive of the eastbound train. Diesel fuel from the damaged southbound train ignited and damaged railcars in the immediate area. No further details were provided that could be used to refine an estimate for the number of railcars affected by severe fire.

In estimating the number of railcars affected by fire, it is assumed that the highest number of railcars affected by fire would occur when derailed cars were in a dense accordion arrangement in the vicinity of the derailed locomotives (source of fuel). Using this assumption, it is reasonable to assume that two or three railcars could have been significantly engulfed in prolonged fires. On this basis, it is estimated that three railcars were affected by severe fires. This accident is noteworthy because the fuel from the fire was not associated with the release of HAZMAT from transported freight.

Delia, Kansas, July 2, 1997

On July 2, 1997, in Delia, Kansas, a train traveling on a side rail collided with the sixth railcar of the train on the main line. The collision resulted in the derailment of 15 railcars from the train on the main line and 3 railcars and 2 locomotives from the train on the side rail. A fire then immediately erupted, “engulfing the derailed cars and locomotives of both trains” (National Transportation Safety Board, 1999). The accident speed was 113 and 24 km/h [70 and 15 mph] for the main line and side line trains, respectively. The fire was fueled by the release of diesel from the damaged locomotive.

Similar to the Momence, Illinois, accident, details about the fire are limited. In estimating the number of railcars affected by fire, it is assumed that the highest number of railcars affected by fire would occur when derailed cars were in a dense accordion arrangement in the vicinity of the derailed locomotives (source of fuel). Using this assumption, it is reasonable to assume that two or three railcars could have been significantly engulfed in prolonged fires. On this basis, it is estimated that three railcars were affected by severe fires.

This accident is noteworthy because one of the cars affected by fire contained 18 medical isotope generators (molybdenum 99 → technetium 99), all of which were spent.
Eight packages were shipped as Radioactive YELLOW-II and 10 were shipped as Radioactive WHITE-I material.[1]

[1]From 49 CFR 172.403 for the maximum radiation level at any point on the external surface of greater than 0.005 mSv/h [0.5 mrem/h] but less than or equal to 0.5 mSv/h [50 mrem/h], the package of radioactive material is labeled YELLOW-II; less than or equal to 0.005 mSv/h [0.5 mrem/h], the package is labeled WHITE-I.

3.3 Frequency of Severe Railway Accidents

Table 3-1 includes the multiple-car HAZMAT release accidents that occurred in the last 12 years involving a severe fire that were described in Section 3.2.

Table 3-1. Summary of Severe Railway Accidents From 1997 to 2008

Year	Million Freight Train Miles*	Severe Fire Incidents		Frequency†
		Widespread	Local	
1997	512	0	0	0
1998	520	0	0	0
1999	542	0	0	0
2000	549	1	0	0.002
2001	538	0	1	0.002
2002	547	0	0	0
2003	561	0	1	0.002
2004	584	0	1	0.002
2005	597	0	1	0.002
2006	624	1	0	0.002
2007	586	0	3	0.005
2008	565	0	0	0
Total	6,725	9		0.001‡

*To convert to kilometers, multiply by 1.609.
†Accidents per million freight train-mi. To convert to accidents per million freight train-km, divide by 1.609.
‡Assuming a Poisson distribution based on severe fires being independent rare events and assuming the accident rate is approximately constant over the 12 years, for a 95 percent confidence interval, the lower limit is 6.1×10^{-4} accidents per million freight train-mi and the upper limit is 2.5×10^{-3} accidents per million freight train-mi.

For the 20 multiple-car HAZMAT release accidents resulting in a fire over the last 12 years, the fire was severe in about half of them. Eight of the nine accidents occurred on the main line. One accident occurred off the main line in 2004. As shown in Table 3-1, on average for the last 12 years, fewer than one severe fire accident (i.e., 0.75) occurred per year with an overall frequency of roughly 6.2×10^{-4} accidents per million freight train-km [1×10^{-3} accidents per million freight train-mi]. In 2007, however, the number of severe fire accidents was significantly greater, with one-third of the severe fire accidents occurring in that year alone.

3.4 Severe Fire Accident Parameter Trends

During the investigation of railway accidents that involved potentially severe fires, the accidents naturally distributed themselves into three categories: (i) widespread severe fires, (ii) local severe fires, and (iii) no severe fires. The following sections describe the parametric trends associated with each of these categories.

3.4.1 Widespread Severe Fire Accidents

Railway fire accidents for which ten or more railcars were conservatively estimated to have been affected by severe fires were placed in a category called widespread severe fires. Of the accidents examined in this analysis, only two fall into this category. The first occurred in New Brighton, Pennsylvania, on October 20, 2006, and the second occurred in Eunice, Louisiana, on May 27, 2000. Accident parameters and values are summarized in Table 3-2. Some values in this table differ slightly from the information in the NTSB reports and described in Section 3.2.2; however, the data was taken from the FRA database to be consistent with Chapter 2. As shown in Table 3-2, the accidents occurred on Class 3 or Class 4 track where nearly 65 percent of the accidents (i.e., 11 out of 17) involving a fire occurred (Figure 2-7). In addition, they occurred at speeds less than 64 km/h [40 mph] where almost half of the accidents (i.e., 8 of the 17) involving a fire occurred (Figure 2-10).

For the accident in Eunice, Louisiana, the rail was misaligned due to broken joint bars (National Transportation Safety Board, 2002). For the accident in New Brighton, Pennsylvania, the rail fractured under the load of the train from an undetected defect (National Transportation Safety Board, 2008). In addition to the parameters listed in Table 3-2, both derailments involved track failure in the vicinity of a bridge. The close proximity of bridges contributed to the severity of both of these accidents by providing conditions that were favorable for the formation of dense railcar heaps. In both of these accidents, railcars were piled on top of other railcars. Thus, when fires fueled by flammable liquids occurred, railcars were in closer proximity to the fires and the severity of the fires tended to be more intense. The resulting intense fires and less manageable railcar configurations also contributed to longer duration fires and extended accident containment times.

Table 3-2. Parameters for Accidents Involving Widespread Railcar Severe Fires

Parameters	New Brighton, Pennsylvania	Eunice, Louisiana
Speed (mph)*	37	39
Total Number of Cars	83	113
Number of Cars Derailed	23	32
Number of HAZMAT Cars	80	56
Number of HAZMAT Cars Releasing	20	18
Track Class	4	3
*To convert to km/h, multiply by 1.609		

Another key factor contributing to the severity of these accidents was the amount of flammable HAZMAT these trains transported. Table 3-2 provides the total number of railcars and the number of railcars carrying HAZMAT for the trains involved in these accidents. From this information, it is clear that both trains were largely composed of cars containing HAZMAT. In addition, as discussed in Section 3.2.2, several cars were carrying flammable materials, and as shown in Appendix A, Table A–1, both trains released thousands of gallons of flammable liquid (i.e., Class 3 HAZMAT). Note that the trains involved in these accidents were likely either “unit” trains, specifically for the New Brighton accident, or “key” trains, and that SNF transportation on these types of trains would be unlikely or would occur under more stringent regulations.

3.4.2 Local Severe Fire Accidents

For accidents involving severe fires that affected some of the railcars (i.e., local severe fires), six occurred on the main line and one occurred off the main line in a rail yard. Five of the six accidents involved a derailment with the remaining one, a head-on-collision. The accident in the rail yard involved an impact. Table 3-3 lists parameters associated with the five severe fire accidents involving a derailment. Similar to Table 3-2, some values in Table 3-3 differ slightly from the information in the NTSB reports and describe in Section 3.2.3; however, the data was taken from the FRA database to be consistent with Chapter 2.

As shown in Table 3-3, many of the parameters in the left four accidents (i.e., those occurring in 2003 and 2007) are similar. These accidents occurred at speeds above 64 km/h [40 mph] where more than half of the accidents (i.e., 9 out of 17) involving a fire occurred (Figure 2-10). They occurred on Class 4 track where almost half of the accidents (i.e., 8 out of 17) involving a fire occurred (Figure 2-7). They involved a HAZMAT release from 5 to 7 cars, and as shown in Figure 2-4, a fire resulted approximately 41 percent of the time (i.e., 7 accidents out of 17) when HAZMAT was released from 5 to 7 cars. As shown in Table 2-3, the four accidents all involved the release of Class 3 HAZMAT (i.e., flammable liquid) and three out of the four also involved the release of Class 2.1 HAZMAT (i.e., flammable gas). In Appendix A, Table A–1 shows that all four accidents resulted in the release of thousands of gallons of flammable liquid or flammable gas.

Table 3-3. Parameters for Accidents Involving Severe Fires (Derailments)

Parameters	Painesville, Ohio	Oneida, New York	Brooks, Kentucky	Tamaroa, Illinois	Baltimore, Maryland
Date	**10/10/2007**	**3/12/2007**	**1/16/2007**	**2/9/2003**	**7/18/2001**
Speed (mph)	48	47	47	42	18
Total Number of Cars	112	78	80	102	60
Number of Cars Derailed	31	29	26	22	11
Number of HAZMAT Cars	40	42	15	50	9
Number of HAZMAT Cars Releasing	5	6	7	7	4
Track Class	4	4	4	4	2
*To convert to km/h, multiply by 1.609					

The Baltimore, Maryland, accident in Table 3-3 occurred at a lower speed, on Class 2 track, and involved a release from a fewer number of cars. Unlike the other accidents in Table 3-3, the accident in Baltimore, Maryland, occurred in a tunnel. The constrained environment contributed to making this accident a severe fire because smoke and heat in the tunnel limited access to the fire.

The four severe fire accidents involving a derailment that did not occur in a tunnel are characterized by train speeds greater than 64 km/h [40 mph] and a HAZMAT release from five or more cars in which a significant amount of flammable liquid or gas was released. The accident occurring in Brooks, Kentucky, was caused by the failure of a railcar truck. The other three accidents were caused by rail failure.

3.4.3 Summary of Severe Fire Accident Parameter Trends

Severe fire accidents (both widespread and local accidents) are generally characterized by derailments in which HAZMAT was released from several cars (i.e., five or more cars). The release involved thousands of gallons of flammable liquid or gas. In general, these accidents were caused by rail failure. As summarized in Tables 3-2 and 3-3, they generally occurred at speeds from just below 64 km/h [40 mph] to just below 80 km/h [50 mph] and typically occurred on Class 3 or Class 4 track.

4 CONCLUSIONS

Based on NAS recommendations, NRC is in the process of determining the types of accident parameters that could potentially impact the rail transport of SNF. This study has been performed to update the frequency analyses of railway accidents. Results suggest that in the previous 12 years, the freight train accident frequency is roughly 1.8 accidents per million freight train-km [2.88 accidents per million freight train-mi]. This result is comparable to the previous study by EPRI, which calculated 1.7 accidents per million freight train-km [2.67 accidents per million freight train-mi]. In addition, the accident frequency has declined significantly over the last 34 years, from a frequency of 6.4 accidents per million freight train-km [10.35 accidents per million freight train-mi] in 1975 to 1.4 accidents per million freight train-km [2.28 accidents per million freight train-mi] in 2008.

This study further examined the accident frequency associated with fires. The report focused on accidents where multiple-car HAZMAT releases occurred, because these types of accidents would most likely result in a severe, long duration fire. The results indicated that the frequency for multiple-car HAZMAT releases resulting in a fire is 1.9×10^{-3} accidents per million freight train-km [3×10^{-3} accidents per million freight train-mi]. However, the accident frequency increased significantly in the last 2 years (i.e., 2007 and 2008) in which eight of the 20 fire accidents occurred.

The evaluation of fire-related accidents further identified those that were severe. The identification of severe fires was based on (i) the fire being able to fully engulf a railcar for an extended period of time and (ii) the source of fuel for the engulfing fire being derived from another railcar. With these two criteria in place, the frequency for a severe fire was calculated to be 6.2×10^{-4} accidents per million freight train-km [1×10^{-3} accidents per million freight train-mi].

To understand some of the parameters that may lead to a severe fire, accident trends were evaluated. With only nine severe fire accidents in the last 12 years, data are lacking; however, some common factors were identified. The railway severe fire accidents were generally characterized by derailments in which HAZMAT was released from several cars (i.e., five or more cars). The release involved thousands of gallons of flammable liquid or gas and occurred at speeds typically in the range from just below 64 km/h [40 mph] to just below 80 km/h [50 mph].

Based on the analysis of accident data, there is a very small frequency of severe fire accidents and therefore a very small likelihood that an SNF transportation package being transported on rail would be involved in a severe fire. Limiting SNF package transport to trains that are not also carrying flammable liquid or gas (i.e., on dedicated trains) would likely make the likelihood even lower.

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APPENDIX A

ACCIDENTS OCCURRING ON THE MAIN LINE

Table A–1. Multiple-Car Hazardous Material Release Accidents That Occurred on the Main Line From 1997 to 2008

			Track	Speed	Total Cars		HAZMAT Cars			Fire†	Class 2.1		Class 3		Class 4.1	Class 5.1	
Date	Location	Type*	Class	(mph)		Derail		Damage/ Derail	Release		(gal)‡	(cf)§	(gal)	(lb)‖	(gal)	(gal)	(lb)
12/7/2008	Nolan, ND	D	4	55	67	37	24	11	6	Y	450		6,260				
10/23/2008	Caney, OK	D	4	24	110	16	29	7	3	Y			12,000				
8/22/2008	Luther, OK	D	2	19	110	14	13	8	5	Y			80,746				
5/24/2008	Mingo, OH	D	2	24	45	5	6	3	2	U			2				
3/3/2008	Mecca, CA	D	5	46	65	28	7	6	4	N							
12/28/2007	New Florence, PA	D	3	23	41	9	17	8	2	Y			15,000				
10/24/2007	Arkansas City, KS	D	3	19	110	10	32	7	2	N			21				
10/10/2007	Painesville, OH	D	4	48	112	31	40	8	5	Y			55,200				
10/8/2007	Safford, AZ	D	1	10	47	5	20	5	3	U							
7/22/2007	Sullivan, IN	D	2	22	21	8	14	7	2	U			20,000				
5/29/2007	Castleberry, AL	D	4	49	66	26	17	8	3	N			15				
3/12/2007	Oneida, NY	D	4	47	78	29	42	22	6	Y	124,313		3,181				
3/8/2007	Hattiesburg, MS	D	2	11	58	11	28	5	2	N							
1/16/2007	Brooks, KY	D	4	47	80	26	15	12	7	Y	33,635		41,685				
12/7/2006	East Bloomburg, PA	D	3	40	60	21	6	4	2	U							
11/22/2006	New Ulm, MN	D	2	24	66	7	65	7	7	N			24,877				
10/20/2006	New Brighton, PA	D	4	37	83	23	80	23	20	Y			485,278				
7/18/2006	Neosho Rapids, KS	D	4	53	86	12	12	5	3	N			219				
6/30/2006	Emporium, PA	D	3	76	46	31	5	5	3	N							
6/27/2006	Saint Jacob, IL	D	4	54	131	21	19	7	3	N						198,100	
2/9/2006	Pima, AZ	D	1	10	26	8	19	8	6	U							
12/8/2005	Lordsburg, NM	D	1	5	50	5	50	5	3	N							
9/20/2005	Eagle Pass, TX	D	2	10	81	8	6	5	2	N			500				
7/10/2005	Anding, MS	HOC	3	51	137	8	13	5	2	Y	20		15,000				
6/24/2005	Hoxie, AR	D	4	54	84	22	18	4	4	N							
4/21/2005	Tyrone, OK	D	5	70	87	36	12	4	2	N						4,000	
10/25/2004	Detroit, MI	D	4	2	81	9	9	4	2	N			4				
8/8/2004	Newton Hamilton, PA	D	4	47	105	37	5	5	2	N							
7/27/2004	Balaton, MN	D	3	30	75	14	8	8	2	U			15,000				
4/28/2004	Dallas, TX	D	2	17	87	12	7	7	2	N			85				
2/7/2004	Leslie, MD	D	4	44	50	34	13	12	3	N							
1/24/2004	Bylas, AZ	D	1	8	60	6	39	6	5	N							

A–2

Table A–1. Multiple-Car Hazardous Material Release Accidents That Occurred on the Main Line From 1997 to 2008 (continued).

			Track	Speed	Total Cars	HAZMAT Cars	Fire†	Class 2.1	Class 3	Class 4.1	Class 5.1						
Date	Location	Type*	Class	(mph)		Derail		Damage/ Derail	Release		(gal)‡	(cf)§	(gal)	(lb)‖	(gal)	(gal)	(lb)
1/11/2004	Hoyte, TX	D	4	45	87	36	17	11	6	N			94,445				
10/25/2003	Shorters, AL	D	4	49	99	27	43	7	3	Y			57,171				2,500
8/14/2003	Vacherie, LA	D	4	39	131	45	78	23	2	N							
5/8/2003	Matfield Green, KS	D	5	51	118	38	15	5	2	N							
2/9/2003	Tamaroa, IL	D	4	42	102	22	50	19	7	Y	7,000		57,840				
10/22/2002	Coahoma, TX	D	4	41	56	17	28	11	2	N							
10/12/2002	Amite, LA	D	4	28	116	21	64	8	2	N			14,000				
9/15/2002	Boyd, TN	D	4	38	141	25	6	6	2	N							
8/26/2002	Brownsville, TX	D	1	5	124	9	26	9	3	N			5				
8/15/2002	Bozeman, MN	D	3	30	74	28	12	11	3	N							
5/27/2002	Potterville, MI	D	4	55	58	35	14	11	2	N	7,000						
5/7/2002	Bentonia, MS	D	4	36	131	42	19	12	2	N							320
2/7/2002	Argonia, KS	D	5	66	33	19	17	17	7	N			11				
1/18/2002	Minot, ND	D	3	41	112	31	39	15	11	N							
12/23/2001	Rochester, NY	D	2	30	43	29	3	3	2	N			14,150				
11/30/2001	Florence, AZ	D	2	25	59	8	25	2	2	N							
8/30/2001	Mulvane, KS	OBS	5	55	32	10	10	4	3	Y				7,176			
8/10/2001	Emhouse, TX	D	3	23	92	8	23	4	3	N			275				
8/5/2001	Pinehurst, TX	D	3	40	84	21	11	7	2	N			26,500				
7/20/2001	Ruddock, LA	D	4	24	139	26	65	24	4	N			22,881				
7/18/2001	Baltimore, MD	D	2	18	60	11	9	4	4	Y			30,000				
6/17/2001	Wilmington, OH	D	3	30	68	16	7	4	2	N							
4/18/2001	Bussey, IA	D	4	10	86	9	13	9	4	N			26,133				
2/18/2001	Central Junction, AL	D	4	25	58	13	15	3	3	N							350,000
1/17/2001	Loder, OK	D	5	68	73	11	6	3	2	N			150				
1/2/2001	Tucson, AZ	D	3	41	107	19	27	9	3	N							
12/21/2000	Philadelphia, PA	D	2	18	39	12	37	12	2	N							
12/18/2000	Plymouth, MN	D	2	25	102	28	102	28	6	Y					19,000		
11/9/2000	Pima, AZ	D	X	10	28	3	15	3	2	U							
11/4/2000	Scotts Bluff, NB	D	4	50	79	18	21	10	5	N			150,020				
9/3/2000	Dacula, GA	D	3	37	38	15	31	13	6	N			28,500				
7/10/2000	Ibis, CA	D	4	30	48	3	14	3	2	N			21				
5/27/2000	Eunice, LA	D	3	39	113	32	56	18	18	Y		6,885	125,130				

Table A–1. Multiple-Car Hazardous Material Release Accidents That Occurred on the Main Line From 1997 to 2008 (continued).																	
			Track	Speed	Total Cars	HAZMAT Cars	Fire†	Class 2.1	Class 3	Class 4.1	Class 5.1						
Date	Location	Type*	Class	(mph)		Derail		Damage/ Derail	Release		(gal‡)	(cf)§	(gal)	(lb)‖	(gal)	(gal)	(lb)
5/6/2000	Mt. Hebron, AL	D	3	38	107	25	4	4	3	N						48,263	50,525
4/22/2000	Yampai, AZ	D	4	19	94	10	29	4	2	N			10,200				
3/21/2000	North Power, OR	D	5	69	80	38	3	2	2	N			73				
2/1/2000	Parmele, NC	D	3	32	39	14	12	6	2	N							
10/31/1999	Canyon, AK	D	2	18	49	10	46	10	6	N			3,140				
9/30/1999	Drummond, MT	D	4	60	115	46	20	7	2	N			26,033				
7/13/1999	Lawler, IA	D	3	29	76	24	3	3	2	N			45,200				
7/11/1999	Paradise, MT	D	4	43	74	29	6	6	5	N							
7/2/1999	Hamlet, NC	D	2	10	158	12	44	8	2	N			1,000				
3/24/1999	Wartrace, TN	D	4	44	74	8	25	8	4	N							
1/9/1999	Milford, NE	D	5	38	124	15	9	9	5	N			109,000				
12/2/1998	Crenshaw, MS	D	4	26	151	8	72	6	3	N							
9/25/1998	De Quincy, LA	D	4	53	24	20	4	2	2	U							
9/2/1998	Crisfield, KS	D	5	69	59	4	5	3	3	Y			1	2,965			
6/29/1998	South Bend, NE	D	4	30	94	26	4	4	2	N							
6/29/1998	Page, WA	D	3	37	57	19	12	6	3	N							1,200
6/26/1998	Niota, IL	SC	5	28	64	6	6	6	4	Y			82				
6/20/1998	Cox Landing, WV	D	3	27	149	20	48	11	2	N							
3/18/1998	Cheraw, SC	D	4	45	32	17	11	9	3	N							
7/18/1997	Flora, MS	D	4	27	125	12	25	2	2	N			1,500				
6/12/1997	Nampa, ID	D	4	22	67	7	9	3	3	N							
5/25/1997	Bauxite, AR	OI	1	7	12	0	2	2	2	N							
3/30/1997	Ridgecrest, NC	D	4	54	54	42	4	3	2	N							
1/22/1997	Appleby, TX	D	3	38	31	13	8	8	2	N							

*Type: D = derailment, OBS = obstruction, HOC = head-on collision, SC = side collision, OI = other impacts
†Fire: Y = yes, N = no, U = undetermined
‡To convert to liters, multiply by 3.785
§ To convert to cubic meters, multiply by 2.83×10^{-2}
‖To convert to kilograms, multiply by 0.4536

APPENDIX B

ACCIDENTS OCCURRING OFF THE MAIN LINE

Table B–1. Multiple-Car Hazardous Material Release Accidents That Occurred Off the Main Line From 1997 to 2008

			Track*	Total Cars		HAZMAT Cars			Fire†	Class 2.1		Class 3		Class 4.1	Class 5.1	
Date	Location	Type‡			Derail		Damage/ Derail	Release		(gal) §	(cf) ‖	(gal)	(lb)¶	(gal)	(gal)	(lb)
12/1/2008	Birmingham, AL	SC	y	114	1	3	2	2	N							6
10/22/2007	Middlebury, VT	D	y	25	24	15	15	4	Y			500				
8/25/2007	Knoxville, TN	D	y	91	5	58	3	2	N			1				
5/31/2007	Walbridge, OH	D	y	75	8	10	8	4	N			203				
12/25/2006	Amarillo, TX	D	y	140	5	24	2	2	N			5				
12/5/2006	Memphis, TN	D	y	92	8	11	3	2	N							
10/25/2006	Livonia, LA	D	y	59	6	14	2	2	N							
3/28/2006	Sahuarita, AZ	D	i	18	2	18	2	2	U							
8/26/2005	Willow Springs, MO	D	s	103	16	9	3	2	N						280	
8/6/2005	Portland, OR	D	y	77	5	9	5	2	N			30				
6/24/2005	Worland, WY	D	s	38	4	27	4	2	N			3				
4/15/2005	Delpro, AR	D	i	15	7	4	4	2	N			1				
1/8/2005	Seabrook, TX	D	i	50	3	13	3	2	Y			1,200			100	
12/12/2004	Big Stone City, SD	U	i	2	2	2	2	2	N			955				
9/21/2004	East St. Louis, IL	OI	y	3	2	3	2	2	Y			48,167				
6/7/2004	Vancouver, WA	D	y	65	5	9	5	2	N			1				
4/11/2003	Slaton, TX	D	y	149	6	5	4	2	N			10,234				
8/31/2001	Slaton, TX	D	y	70	4	2	1	2	N			3,001				
6/17/2001	Carson, CA	D	y	25	4	12	4	2	U			2				
3/25/2001	Wamsutter, WY	D	s	112	14	4	4	2	N							
7/11/2000	Columbus, OH	D	y	125	5	37	5	2	N			10				
12/22/1999	Talkeetna, AK	D	y	49	15	41	15	14	N			120,000				
3/23/1999	Bedford Park, IL	D	y	30	5	6	2	2	U							
12/12/1998	Riverdale, IL	RC	y	33	5	7	2	2	U							
10/20/1998	Austin, TX	D	y	17	4	3	3	3	U							
10/6/1998	Camden, AR	D	y	63	4	4	4	2	N							3,000
8/16/1998	Panhandle, TX	OI	s	20	6	6	6	2	N			18,000				
5/21/1998	Englewood, TX	D	y	77	5	20	5	2	N							
4/19/1998	Henderson, NV	D	i	7	3	7	5	5	N							
6/22/1997	Bowie, AZ	D	y	74	3	38	3	2	U							

*Track: m = main, i = industry, y = yard, s = siding
†Fire: Y = yes, N = no, U = undetermined
‡Type: D = derailment, OBS = obstruction, HOC = head-on collision, SC = side collision, OI = other impacts, RC = raking collision
§To convert to liters, multiply by 3.785
‖To convert to cubic meters, multiply by 2.83×10^{-2}
¶To convert to kilograms, multiply by 0.4536