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NUREG/CR-7035

Analysis of Severe Roadway Accidents Involving Long Duration Fires

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Analysis of Severe Roadway Accidents Involving Long Duration Fires

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Manuscript Completed: December 2010
Date Published: February 2011

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Office of Nuclear Material Safety and Safeguards

ABSTRACT

10 CFR Part 71 provides the regulatory requirements for the certification of transportation packages for spent nuclear fuel (SNF) and radioactive material. SNF packages are expected to be designed to endure a fully engulfing fire, as prescribed in 10 CFR Part 71. As a regulatory authority for transportation of radioactive materials, the U.S. Nuclear Regulatory Commission (NRC) ensures that packages designed to transport SNF meet the regulations prescribed in 10 CFR Part 71. The purpose of the study described in this report was to support NRC in determining the different types and frequency of roadway accidents involving severe, long duration fires that could impact roadway transport of SNF. Roadway accident data were examined from the U.S. Department of Transportation—Pipeline and Hazardous Materials Safety Administration. This study focused on those in-transit hazardous material (HAZMAT) accidents resulting in a fire that involved more than one vehicle. Such fires were analyzed to identify those that could have been severe enough to potentially affect an SNF package being transported on a roadway where the source of fuel for the fire would be from a vehicle not carrying the SNF package. From this study, the frequency of a severe fire occurring was estimated as roughly 4.90×10^{-5} accidents per million HAZMAT vehicle-km [7.89×10^{-5} accidents per million HAZMAT vehicle-mi]. This frequency represents 23 severe fire accidents occurring over the last 12 years (i.e., 1997 to 2008). None of the severe fire accidents involved the release of radioactive material. In general, severe fires are characterized by the release of flammable liquid (i.e., Class 3 HAZMAT), and in about 40 percent of the severe fires, more than 22,710 L [6,000 gal] of flammable liquid was released. Also, about half of the severe fires occurred on interstate highways with a median or divider and two of the severe fires occurred on interstate ramps. One of these accidents, occurring on a ramp, was likely in an enclosed area and as a result had the potential to generate a fire with higher average temperatures.

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EXECUTIVE SUMMARY

As a regulatory authority for transportation of radioactive materials in the United States, 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 may exceed the current regulations. The purpose of the study described in this report was to support NRC in determining the different types and frequency of roadway accidents involving severe, long duration fires that could impact SNF transport on roadways.

To perform this study, roadway accidents from the past 12 years (i.e., 1997 to 2008) were analyzed to estimate the accident frequency involving hazardous material (HAZMAT) releases. Roadway accident data were obtained from the U.S. Department of Transportation—Pipeline and Hazardous Materials Safety Administration with vehicle mileage data obtained from the U.S. Census Bureau and the Bureau of Transportation Statistics. Based on this information, more than 23,000 in-transit HAZMAT accidents occurred in the past 12 years, resulting in a frequency of approximately 4.92×10^{-2} accidents per million HAZMAT vehicle-km [7.92×10^{-2} accidents per million HAZMAT vehicle-mi].

Most of the report focuses on the review of in-transit fires involving more than one vehicle because these types of accidents would most likely result in a transportation package being exposed to a fire. This assumes that a transportation package would not provide fuel to a fire and that it would be unlikely for fuel from the truck transporting the SNF to leak from a ruptured fuel tank, leak under the package, and fully engulf it in a fire. For in-transit fires, the frequency was approximately 1.02×10^{-3} accidents per million HAZMAT vehicle-km [1.64×10^{-3} accidents per million HAZMAT vehicle-mi], and for those fires involving more than one vehicle, the frequency was approximately 2.98×10^{-4} accidents per million HAZMAT vehicle-km [4.8×10^{-4} accidents per million HAZMAT vehicle-mi]. In addition, roadway accidents for the past 12 years were analyzed in more detail to identify those accidents involving a severe fire and to estimate the severe accident frequency.

During the last 12 years, 477 in-transit roadway accidents resulted in a fire and 140 of them involved more than 1 vehicle. Out of these 140 fires, only 23 were identified as severe. The identification of a severe fire was based on the following criteria: (i) the principal source of fuel for the engulfing fire was from another vehicle, (ii) fuel was flammable liquid that could pool under another vehicle, (iii) the accident involved more than one vehicle but not collisions of a vehicle with a train, and (iv) the fire persisted for an extended period of time. Using these four criteria, on average, two severe fire accidents occurred per year resulting in a frequency of approximately 4.90×10^{-5} accidents per million HAZMAT vehicle-km [7.89×10^{-5} accidents per million HAZMAT vehicle-mi].

In addition to calculating the frequency, severe fire accidents were analyzed to identify trends in the data. In general, severe fires are characterized by the release of flammable liquid (i.e., Class 3 HAZMAT), and in about 40 percent of the severe fires, more than 22,710 L [6,000 gal] of flammable liquid were released. Also, about half of the severe fires occurred on interstate highways with a median or divider and 2 out of the 23 severe fires occurred on interstate ramps. Accident descriptions are brief, so it is difficult to determine with certainty, however, one of these accidents on a ramp was likely in an enclosed area because of its location on the highway ramp and as such potentially led to a hotter fire. Consistent with their

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 M. Necsoiu for data retrieval, A. Ghosh for technical review, S. Mohanty for programmatic review, and L. Mulverhill for editorial review. The authors also appreciate A. Ramos 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.

ANALYSES AND CODES: Microsoft® Office Excel® 2003 (Microsoft, 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
CNWRA	Center for Nuclear Waste Regulatory Analyses
BTS	Bureau of Transportation Statistics
DOE	U.S. Department of Energy
HAC	Hypothetical Accident Condition
HAZMAT	Hazardous Material
NAS	National Academy of Sciences
NRC	U.S. Nuclear Regulatory Commission
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
SFST	Spent Fuel Storage and Transportation
SNF	Spent Nuclear Fuel
WIPP	Waste Isolation Pilot Plant

1 INTRODUCTION

1.1 Historical Review of Roadway Accident Data

The U.S. Nuclear Regulatory Commission (NRC) currently shares regulatory authority for the packaging and transportation of high-level radioactive materials with the U.S. Department of Transportation. Under the NRC regulations in 10 CFR Part 71, a spent nuclear fuel (SNF) transportation package must be designed to withstand hypothetical accident conditions (HACs), including dropping, crushing, puncturing, engulfing fire, and immersing in water. The current regulations 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 not less than 30 minutes. Once subjected to this HAC 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 on transportation of radioactive waste. 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 to transport 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 social and institutional challenges must be resolved 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, 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. Both of these accidents are included in Section 3.2.3 of this report. In addition to these two roadway accidents, NRC had evaluated long duration fire events (i.e., longer than 30 minutes exposure) 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. Neither of these two accidents is included in this report because one of them was a railway accident and the other one occurred more than 12 years ago. However, all four accidents are noteworthy because 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. Note, 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 transportation of SNF. The likelihood that one of these severe accidents could occur 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 to occur and the consequence of this accident. This report examined the accident rates for aircraft, truck, rail, helicopter, and ship. For truck accidents, the severity was based upon the crush force and fire duration at a temperature of 1,027 °C [1,880 °F]. The crush force ranged from 0 to 2.22×10^6 newtons and was divided into 7 classes of severity. As indicated, the classification of the accident severity was also dependent upon the fire duration. The classification based on fire duration was evenly distributed roughly every 30 minutes. The NRC study based its accident frequency on "Quantitative Characterization of the Environment Experienced by Cargo in Motor Carrier Accidents" (Foley, et al., 1974), which calculated accident frequencies based upon accident rates reported for intercity shipments of property by Class I and II Interstate Motor Carriers. Based upon the data Foley, et al. (1974) developed; the overall frequency used was 1.1×10^{-6} accidents per vehicle-km [1.7×10^{-6} accidents per vehicle-mi].

Additionally, NUREG/CR–4829, "Shipping Container Response to Severe Highway and Railway Accident Conditions," (Fischer, et al., 1988) evaluated the response of spent fuel packages exposed to severe highway and railway accident conditions if a severe accident occurred during the shipment of SNF. In this evaluation, roadway accident rates are highly variable and depend upon many elements including road type, vehicle type, regulations, and driving practices. The analyses in the Fischer, et al. (1988) report derived two accident rates from different sources. The first source was the U.S. Department of Transportation, Federal Motor Carrier Safety Administration for all roadways. The data analyzed from this source spanned the time between 1960 and 1972. The calculated frequency for this time range was 1.6×10^{-6} accidents per vehicle-km [2.5×10^{-6} accidents per vehicle-mi]. The U.S. Department of Transportation, Federal Motor Carrier Safety Administration data included all truck and carrier types of accidents. The analyses in the same NRC (1988) report included a second source: American Petroleum Institute data from 1968 through 1981 for all roadways. The accident frequency from this second data source was calculated to be 4.0×10^{-6} accidents per vehicle-km [6.4×10^{-6} accidents per vehicle-mi]. For the Fischer, et al. (1988) report, the American Petroleum Institute accident rate was used as the estimate for spent fuel truck accident rates, because it was assumed that these data were more reliable and the transportation would be more consistent with that used to transport SNF packages.

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 evaluated various reports that had reviewed frequencies of past roadway accident rates. Sprung, et al. (2000) indicated that the most comprehensive data set available at the time was from the U.S. Department of Transportation, Federal Motor Carrier Safety Administration. Also, Sprung, et al. (2000) indicated that Argonne National Laboratory (ANL) had reviewed accident data between the years 1984 and 1986 through 1988 using the U.S. Department of Transportation data in ANL/ASD/TN–150, "State-Level Accident Rates of Surface Freight Transportation: A Reexamination" (Saricks and Tompkins, 1999). The resulting accident frequency from the ANL review was 3.6×10^{-7} accidents per vehicle-km [5.8×10^{-7} accidents per vehicle-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 roadway freight accidents based upon ANL/ASD/TN–150 (Saricks and Tompkins, 1999). The roadway accident rates were based on statistics the U.S. Department of

Transportation, Federal Motor Carrier Safety Administration compiled from 1994 through 1996. From the data, the composite mean frequency was calculated as 3.2×10^{-7} accidents per vehicle-km [5.2×10^{-7} accidents per vehicle-mi].

These previous reports are compared in Table 1-1, which indicates that the earlier studies had a slightly higher accident frequency per vehicle mile than the later studies. This may have been the result of the changes in the regulations or automotive advancements that have increased the safety of roadway travel over the past 30 years. As Table 1-1 shows, the main source of information for accident frequency was data from the U.S. Department of Transportation, Federal Motor Carrier Safety Administration. However, some studies, including Fischer, et al. (1998), used other sources of information, such as the American Petroleum Institute.

Table 1-1. Comparison of Roadway Accident Frequencies

Source Document	Source of Data	Reported Accident Frequency (Accidents/Vehicle-mi)*
NUREG–0170†	SAN074–0001‡	1.7×10^{-6}
NUREG/CR–4829§	U.S. Department of Transportation, Federal Motor Carrier Safety Administration, 1960–1972	2.5×10^{-6}
NUREG/CR–4829§	American Petroleum Institute, 1968–1981	4.0×10^{-6}
NUREG/CR–6672‖	U.S. Department of Transportation Office of Motor Carriers, 1984 and 1986–1988	5.8×10^{-7}
DOE/EIS–0250¶	U.S. Department of Transportation Office of Motor Carriers, 1994–1996	5.2×10^{-7}

*To convert to accidents/vehicle-km divide by 1.609
†NRC. NUREG–0170, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes." Washington, DC: U.S. Nuclear Regulatory Commission. December 1977.
‡Clarke, R.K., J.T. Folwy, W.F. Hartman, and D.W. Larson. "Severities of Transportation Accidents, Volume I: Summary." SAND74–0001. Albuquerque, New Mexico: Sandia Laboratories. 1975.
§Fischer, L.E., C.K. Chou, M.A. Gerhard, C.Y. Kimura, R.W. Martin, R.W. Mensing, M.E. Mount, and M.C. Witte. NUREG/CR–4829, "Shipping Container Response to Severe Highway and Railway Accidents Conditions." Washington, DC: U.S. Nuclear Regulatory Commission. 1988.
‖Sprung, J.L., D.J. Ammerman, J.A. Koski, and F.R. Weiner. NUREG/CR–6672, "Reexamination of Spent Fuel Shipment Risk Estimates." Washington, DC: U.S. Nuclear Regulatory Commission. 2000.
¶DOE. 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." Las Vegas, Nevada: DOE, Office of Civilian Radioactive Waste Management. February 2002.

1.2 Objective

The objective of this study is to support the NRC Division of Spent Fuel Storage and Transportation (SFST) in its review of severe roadway transportation accidents involving long duration fires. SFST develops and implements 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 roadway accidents carrying flammable hazardous material (HAZMAT) that resulted in a long duration fire and assess possible trends associated with roadway accidents involving long duration fires.

1.3 Scope and Organization of the Report

As will be described in Chapter 2 of this report, more than 23,000 reported in-transit[1] accidents occurred between 1997 and 2008 that involved HAZMAT. Many of these were minor releases or there was not a release, and only 59 involved radioactive materials. Analyzing the roadway accident statistics and determining whether there are any trends in the data can support NRC evaluations of current and future regulations associated with transportation of SNF.

This report focuses on the statistics and trends of historical roadway accident data. The document is organized into four chapters, including this chapter (Chapter 1, Introduction). Historical roadway accident data are reviewed in Chapter 2. Chapter 2 also evaluates accident frequency from the U.S. Department of Transportation, 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.

[1]As stated in PHMSA (2004), in-transit means the incident occurred or was first discovered while the package was in the process of being transported.

2 DATA ANALYSIS

The regulations at 49 CFR 171.15 and 49 CFR 171.16 govern the reporting of HAZMAT incidents. Using information primarily from PHMSA, the data analysis in this chapter focuses on roadway in-transit HAZMAT incidents involving a fire. Those in-transit fires involving more than one vehicle were further analyzed in Chapter 3 to identify which accidents would include severe fires. Although the regulations and the information obtained from PHMSA are in terms of HAZMAT incidents, the term "accident" is used instead of "incident" in the remainder of this chapter for consistency with the rest of this report and the studies described in Chapter 1.

In-transit fires involving more than one vehicle were reviewed to understand how a truck carrying an SNF package could be involved in a fully engulfing fire. As will be later described in Chapter 3, for the fire to be a severe fire and provide sufficient fuel for a fully engulfing fire, the source of fuel needs to come from another vehicle such as a truck loaded with Class 3 HAZMAT (i.e., flammable liquid). In-transit fires involving more than one vehicle included collisions between a truck carrying HAZMAT and a train, a truck carrying HAZMAT and another truck, and a truck carrying HAZMAT and a car. However, in-transit fires involving more than one vehicle were not just limited to collisions but also included another vehicle swerving in front of a truck carrying HAZMAT. Noncollision accidents were considered because in some cases, it was not clear from the accident description whether a collision actually occurred when a vehicle swerved in front of the truck carrying HAZMAT and it was important to consider another vehicle being involved in the fire whether or not a collision actually occurred. Instead of more narrowly defining the data set, the individual in-transit fires involving more than one vehicle were analyzed further using the criteria described in Chapter 3 and then narrowed down to identify the ones that were severe fires.

2.1 Data Sources

PHMSA compiles information on HAZMAT accidents in summary reports (PHMSA, 2010a) and in an online searchable database (PHMSA, 2010b). The number of in-transit HAZMAT accidents and the number of in-transit fires from 1998 to 2008 were obtained using the PHMSA summary reports and online database. However, 1997 data were requested directly from PHMSA because they could not be downloaded from the website.

Data for number of vehicle miles were used to calculate the frequency for in-transit HAZMAT accidents. Data for vehicle miles were obtained from the Bureau of Transportation Statistics (BTS, 2010), and HAZMAT vehicle miles were obtained from the U.S. Census Bureau (2004).

2.2 Data Screening

The data analysis focused on in-transit HAZMAT highway accidents obtained from PHMSA (2010b). In-transit highway accidents were downloaded from PHMSA for 1998 to 2008 in a comma-separated value file and then analyzed in Microsoft® Excel®. Duplicate records for an individual accident were identified by matching the record numbers and also by using a field in the database that identified these multiple records. Those in-transit accidents involving fires were then separated from the larger data set, placed in a separate Excel file, and analyzed to determine the type and amount of HAZMAT released.

2.3 Overall Frequency of Hazardous Material Roadway Accidents

Table 2-1 shows the overall frequency of in-transit HAZMAT roadway accidents for the past 12 years (i.e., 1997 to 2008). The last row in the table summarizes total vehicle miles, total accidents, and average frequencies of these accidents. As shown in this table, for the 12 years from 1997 to 2008, the frequency of a HAZMAT accident was approximately 4.92×10^{-2} accidents per million HAZMAT vehicle-km [7.92×10^{-2} accidents per million HAZMAT vehicle-mi]. For in-transit fires, the frequency was approximately 1.02×10^{-3} accidents per million HAZMAT vehicle-km [1.64×10^{-3} accidents per million HAZMAT vehicle-mi], and for those fires involving more than 1 vehicle, the frequency was approximately 2.98×10^{-4} accidents per million HAZMAT vehicle-km [4.8×10^{-4} accidents per million HAZMAT vehicle-mi]. As shown in Table 2-1, the number of in-transit HAZMAT accidents appears to have increased over time, with the number of in-transit accidents in 2008 (i.e., 2,513) about 70 percent greater than the number for 1997 (i.e., 1,494).

Table 2-1. Frequency of In-Transit HAZMAT Roadway Accidents

Year	Million HAZMAT Vehicle Miles*	In-Transit HAZMAT Accidents		In-Transit Fires		In-Transit Fires Involving More Than One Vehicle	
		Number	Frequency†	Number	Frequency†	Number	Frequency†
2008	24,707	2,513	1.02×10^{-1}	40	1.62×10^{-3}	9	3.64×10^{-4}
2007	24,707	2,636	1.07×10^{-1}	38	1.54×10^{-3}	11	4.45×10^{-4}
2006	24,223	2,741	1.13×10^{-1}	32	1.32×10^{-3}	9	3.72×10^{-4}
2005	24,224	2,132	8.80×10^{-2}	39	1.61×10^{-3}	10	4.13×10^{-4}
2004	24,038	1,468	6.11×10^{-2}	46	1.91×10^{-3}	16	6.66×10^{-4}
2003	23,723	1,505	6.34×10^{-2}	43	1.81×10^{-3}	11	4.64×10^{-4}
2002	23,362	1,352	5.79×10^{-2}	34	1.46×10^{-3}	9	3.85×10^{-4}
2001	24,908	1,482	5.95×10^{-2}	45	1.81×10^{-3}	15	6.02×10^{-4}
2000	24,489	1,970	8.04×10^{-2}	56	2.29×10^{-3}	20	8.17×10^{-4}
1999	24,152	1,874	7.76×10^{-2}	38	1.57×10^{-3}	12	4.97×10^{-4}
1998	23,400	1,939	8.29×10^{-2}	29	1.24×10^{-3}	9	3.85×10^{-4}
1997	24,788	1,494	6.03×10^{-2}	37	1.49×10^{-3}	9	3.63×10^{-4}
Summary	291,566	23,106	7.92×10^{-2}	477	1.64×10^{-3}	140	4.80×10^{-4}

*To convert from mi to km, multiply by 1.609.
†Frequency in accidents per million HAZMAT vehicle-mi. To convert to accidents per million HAZMAT vehicle-km, divide by 1.609.

To develop the frequencies in Table 2-1, the number of in-transit accidents was obtained directly from PHMSA; however, HAZMAT vehicle miles had to be estimated because data were available for only 1997 and 2002 from the U.S. Census Bureau (2004). For 1997, the number of HAZMAT vehicle miles was approximately 13 percent of total vehicle miles, and for 2002, the number of HAZMAT vehicle miles was approximately 11 percent of total vehicle miles. Based on this information, the HAZMAT vehicle miles were estimated to be 11 to 12 percent of total vehicle miles for the remaining years. Between 1997 and 2002, the average of 12 percent was used. After 2002, the same percentage for 2002 (i.e., 11 percent) was used. Note that total vehicle miles were not available for 2008; therefore, 2007 data were used. These estimated HAZMAT vehicle miles are shown in Table 2-1.

About 2 percent of the HAZMAT accidents listed in Table 2-1 resulted in an in-transit fire (i.e., 477 out of 23,106). Additionally, about 30 percent of the in-transit fires involved more than 1 vehicle (i.e., 140 out of 477), and in 9 of these fires, the other vehicle was a train. Figure 2-1 shows the number of HAZMAT in-transit fires for the last 12 years. As shown in this figure, in contrast to what appears to be an increasing trend in HAZMAT accidents (Table 2-1), the number of in-transit fires (including those involving more than one vehicle) does not appear to increase or decrease significantly over time. On average, 40 in-transit fires occurred per year, and approximately 30 percent of them (i.e., 12 per year), on average, involved more than 1 vehicle. The number of in-transit fires was the highest in 2000; 56 in-transit fires occurred with approximately 36 percent of them (i.e., 20) involving more than 1 vehicle.

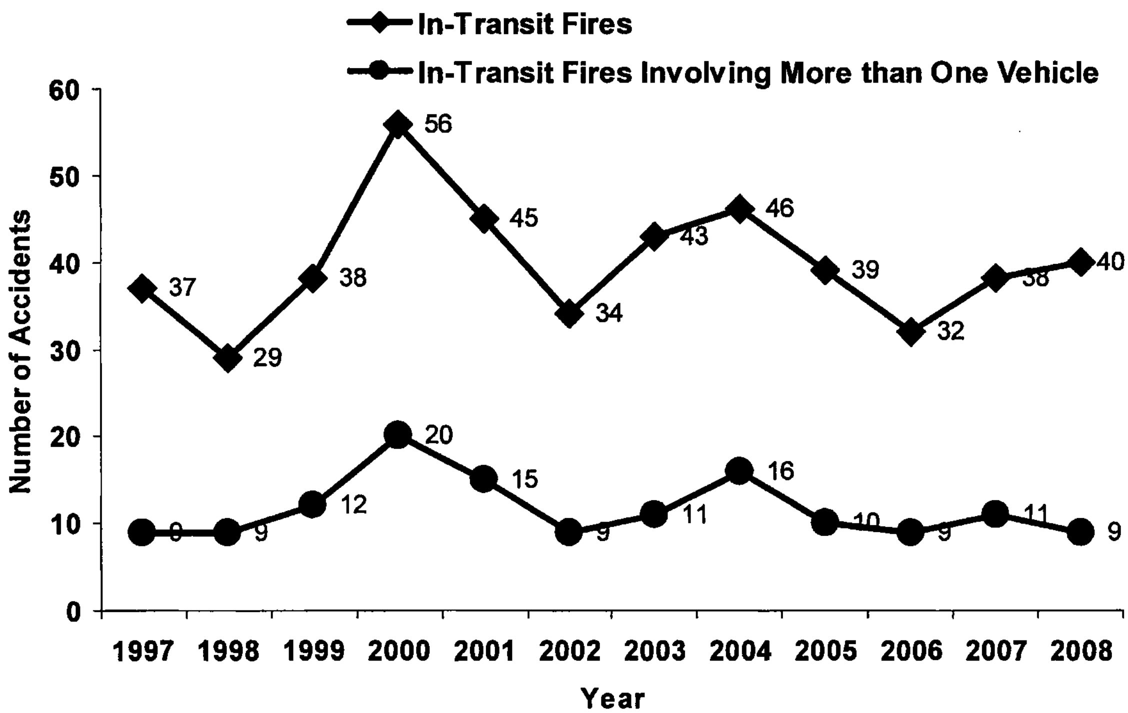

Figure 2-1. Hazardous Material In-Transit Fires

2.4 Data Classification for In-Transit Fires

In-transit fires were analyzed to determine the type and amount of HAZMAT released and the estimated speed of the vehicle carrying the HAZMAT. This data classification was used to help identify trends that may impact the severity of a fire.

2.4.1 Hazardous Material Class

Figure 2-2 shows in-transit fires for HAZMAT classes involving explosives, flammable material, oxidizer, and radioactive material. As determined from this figure and Table 2-1, flammable liquid was involved in about 69 percent (i.e., 329 out of 477) of the in-transit fires; flammable gas was involved in about 8 percent (i.e., 40 out of 477) of the in-transit fires; and oxidizer was involved in about 5 percent (i.e., 22 out of 477) of the in-transit fires. Although only 1 percent of the in-transit fires involved radioactive material (i.e., 5 out of 477), in 1 of these fires, flammable liquid and radioactive material were released.[1] As shown in Figure 2-2, more than 1 vehicle was involved in about 33 percent of the in-transit fires involving flammable gas (i.e., 13 out of 40) or liquid (i.e., 108 out of 329). Additionally, more than 1 vehicle was involved in about 20 percent of the in-transit fires involving explosives (i.e., 1 out of 6), an oxidizer (i.e., 4 out of 22), or radioactive material (i.e., 1 out of 5).

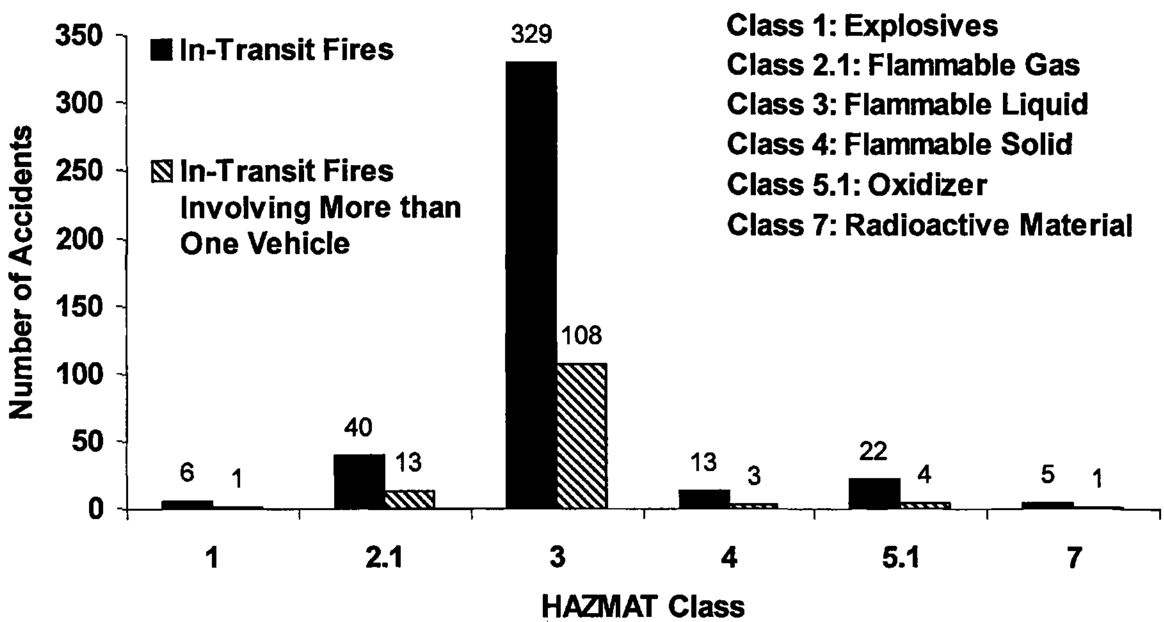

Figure 2-2. In-Transit Fires Separated by Hazardous Material Class. Some Fires Involved More Than One Hazardous Material Class.

[1]For more information on this accident, refer to PHMSA (2010b, Report Number I–2003041380).

2.4.1.1 Radioactive Material Accidents

Figure 2-3 shows the number of radioactive material (i.e., Class 7 HAZMAT) in-transit accidents (with and without a fire) and radioactive material in-transit fires for the past 12 years (i.e., 1997 to 2008). In these 12 years, on average, about 5 in-transit accidents involving radioactive material occurred per year. However, as shown in this figure, the number of in-transit accidents varied greatly from year to year. For example, the number of accidents in 2005 was more than twice the average and just 3 years later in 2008, the number of accidents was less than half the average. From 1997 to 2008, only five in-transit accidents resulted in fires with four of them occurring from 2003 to 2005. The accident occurring in 2003 involved more than one vehicle.

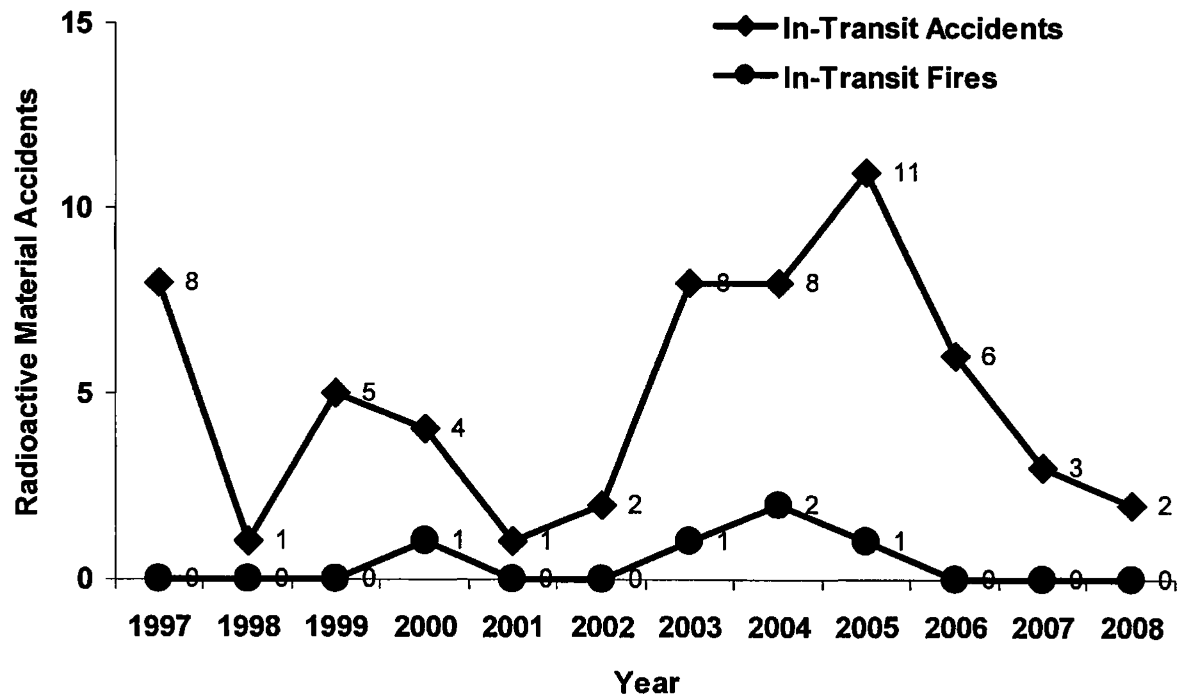

Figure 2-3. Radioactive Material Accidents

Table 2-2 shows the frequency of in-transit radioactive material (i.e., Class 7 HAZMAT) accidents for the past 12 years (i.e., 1997 to 2008). The last row in the table summarizes total vehicles miles, total accidents, and average frequencies of those accidents. As shown in this table, for the 12 years from 1997 to 2008, the frequency of an in-transit radioactive material accident was approximately 7.27×10^{-2} accidents per million Class 7 HAZMAT vehicle-km [1.17×10^{-1} accidents per million Class 7 HAZMAT vehicle-mi]. With 5 in-transit fires occurring over the 12 years, the frequency for an in-transit radioactive material fire accident was approximately 6.18×10^{-3} accidents per million Class 7 HAZMAT vehicle-km [9.95×10^{-3} accidents per million Class 7 HAZMAT vehicle-mi]. Only 1 of these fires involved another vehicle for a frequency of 1.24×10^{-3} accidents per million Class 7 HAZMAT vehicle-km [1.99×10^{-3} accidents per million Class 7 HAZMAT vehicle-mi]. To develop the frequencies in Table 2-2, the number of in-transit radioactive material accidents was obtained directly from PHMSA; however, the number of Class 7 HAZMAT (i.e., radioactive material) vehicle miles had to be estimated because data were available for only 1997 and 2002 from the U.S. Census Bureau (2004, 1999). For 1997, the number of radioactive material vehicle miles was approximately 0.04 percent of total vehicle miles, and for 2002, the number of radioactive material vehicle miles was approximately 0.01 percent of total vehicle miles.

Table 2-2. Frequency of In-Transit Radioactive Material Roadway Accidents

Year	Million Class 7 HAZMAT Vehicle Miles*	In-Transit Radioactive Material Accidents		In-Transit Fires		In-Transit Fires Involving More Than One Vehicle	
		Number	Frequency†	Number	Frequency†	Number	Frequency †
2008	29.7	2	6.73×10^{-2}	0	0.00×10^{0}	0	0.00
2007	29.7	3	1.01×10^{-1}	0	0.00×10^{0}	0	0.00
2006	29.1	6	2.06×10^{-1}	0	0.00×10^{0}	0	0.00
2005	29.1	11	3.78×10^{-1}	1	3.43×10^{-2}	0	0.00
2004	28.9	8	2.77×10^{-1}	2	6.92×10^{-2}	0	0.00
2003	28.5	8	2.80×10^{-1}	1	3.50×10^{-2}	1	3.50×10^{-2}
2002	28.1	2	7.12×10^{-2}	0	0.00×10^{0}	0	0.00
2001	56.6	1	1.77×10^{-2}	0	0.00×10^{0}	0	0.00
2000	55.7	4	7.18×10^{-2}	1	1.80×10^{-2}	0	0.00
1999	54.9	5	9.10×10^{-2}	0	0.00×10^{0}	0	0.00
1998	53.2	1	1.88×10^{-2}	0	0.00×10^{0}	0	0.00
1997	78.7	8	1.02×10^{-1}	0	0.00×10^{0}	0	0.00
Summary	502.4	59	1.17×10^{-1}	5	9.95×10^{-3}	1	1.99×10^{-3}

*To convert from mi to km, multiply by 1.609.
†Frequency in accidents per million Class 7 HAZMAT vehicle-mi. To convert to accidents per million Class 7 HAZMAT vehicle-km divide by 1.609.

Based on this information, the radioactive material vehicle miles were estimated to be 0.01 to 0.03 percent of total vehicle miles for the remaining years. Between 1997 and 2002, the average of 0.03 percent was used. After 2002, the same percentage for 2002 (i.e., 0.01 percent) was used. Note that total vehicle miles were not available for 2008; therefore, 2007 data were used. These estimated Class 7 HAZMAT (i.e., radioactive material) vehicle miles are shown in Table 2-2.

The estimated average frequency of in-transit radioactive material accidents shown in Table 2-2 is comparable within an order of magnitude to the frequency Battelle (2001) estimated. Battelle (2001) calculated an accident rate for Class 7 HAZMAT (i.e., radioactive material) of 2.45×10^{-1} accidents per million Class 7 HAZMAT vehicle-km [3.95×10^{-1} accidents per million Class 7 HAZMAT vehicle-mi] using data from 1990 through 1999. It estimated 12 accidents in 48.9 million km [30.4 million mi], which is comparable to the data for in-transit radioactive material accidents for 2005 shown in Table 2-2. However, the average frequency over 12 years of data in Table 2-2 {7.27×10^{-2} accidents per million Class 7 HAZMAT vehicle-km [1.17×10^{-1} accidents per million Class 7 HAZMAT vehicle-mi]} is smaller by more than a factor of three. At least some of this difference is due to the uncertainty in estimating radioactive material miles. From Table 2-2, on average, radioactive material is estimated to have been transported 67.4 million km [41.9 million mi] annually compared to 48.9 million km [30.4 million mi] estimated by Battelle, an increase of about 38 percent. The larger difference, however, involves the number of in-transit radioactive material accidents. As shown in Table 2-2, on average about 5 in-transit radioactive material accidents were identified from PHMSA per year, which is less than half of the approximately 12 accidents estimated in Battelle (2001).

In addition, based on information from the Waste Isolation Pilot Plant (WIPP), DOE (2009a) identified 8 traffic accidents involving WIPP trucks in the first 10 years of operation. Using shipment information from November 30, 2009 (DOE, 2009b), totaling approximately 15.4 million km [9.6 million loaded mi] and assuming 8 or fewer accidents involving a loaded WIPP truck, the frequency for an accident would be approximately 6.46×10^{-2} to 5.18×10^{-1} accidents per million loaded vehicle-km [1.04×10^{-1} to 8.33×10^{-1} accidents per million loaded vehicle-mi], which is also comparable within an order of magnitude to the average frequency for in-transit radioactive material accidents estimated in Table 2-2.

2.4.1.2 Flammable Liquid Released

As determined from Figure 2-2 and Table 2-1, flammable liquid was involved in about 77 percent (i.e., 108 out of 140) of the in-transit fires involving more than 1 vehicle. Figure 2-4 shows a subset of these 108 in-transit fires because the amount of flammable liquid released was identified in only 98 of the 108 fires. In this figure, the amount of flammable liquid released was arbitrarily separated into 7,570-L [2,000-gal] bins.

As shown in Figure 2-4, in about half of the fires (i.e., 52 out of 98), more than 22,710 L [6,000 gal] of flammable liquid were released. As shown to the far right in this figure, in 1 of these fires, 50,719 L [13,400 gal] were released. Although not shown in this figure, for the lowest bin {i.e., 3.8 to 7,570 L [1 to 2,000 gal]}, about 70 percent of the fires (i.e., 23 out of 33) involved the release of fewer than 1,893 L [500 gal] of flammable liquid.

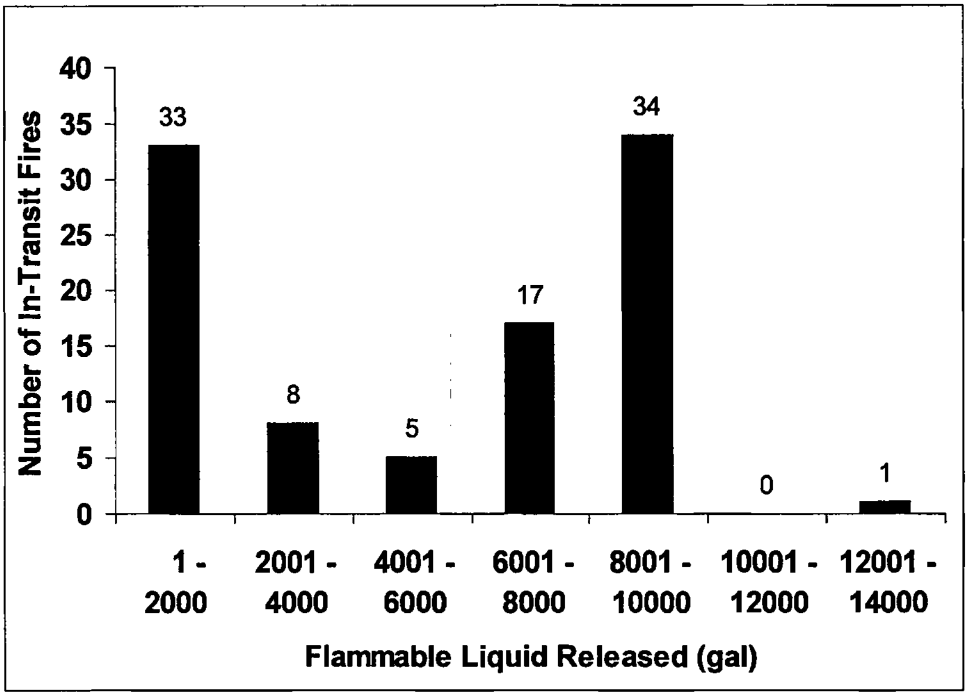

Figure 2-4. Amount of Flammable Liquid Released for In-Transit Fires Involving More Than One Vehicle. To Convert From Gallons to Liters, Multiply by 3.785.

2.4.2 Estimated Speed

Figure 2-5 displays the number of in-transit fires in terms of estimated speed for the vehicle carrying HAZMAT. This figure shows a subset of the in-transit fires because speed information was available for only 330 of the 477 in-transit fires and for only 122 of the 140 in-transit fires involving more than 1 vehicle. The estimated speed was arbitrarily separated into 32-km/h [20-mph] bins. As shown in this figure, most of the in-transit fires occurred in the range from 66 to 97 km/h [41 to 60 mph]. In this range, 37 percent (i.e., 68 out of 182) of the in-transit fires involved more than 1 vehicle. Out of these 68 fires involving more than 1 vehicle, 72 percent of them (i.e., 49 out of 68) involved the release of flammable liquid (Table 2-3). One of these 49 in-transit fires also involved the release of radioactive material. Similarly, in the higher speed range from 98 to 129 km/h [61 to 80 mph], 33 percent (i.e., 15 out of 46) of the in-transit fires involved more than 1 vehicle. Out of these 15 fires involving more than 1 vehicle, 67 percent of them (i.e., 10 out of 15) involved the release of flammable liquid (Table 2-3).

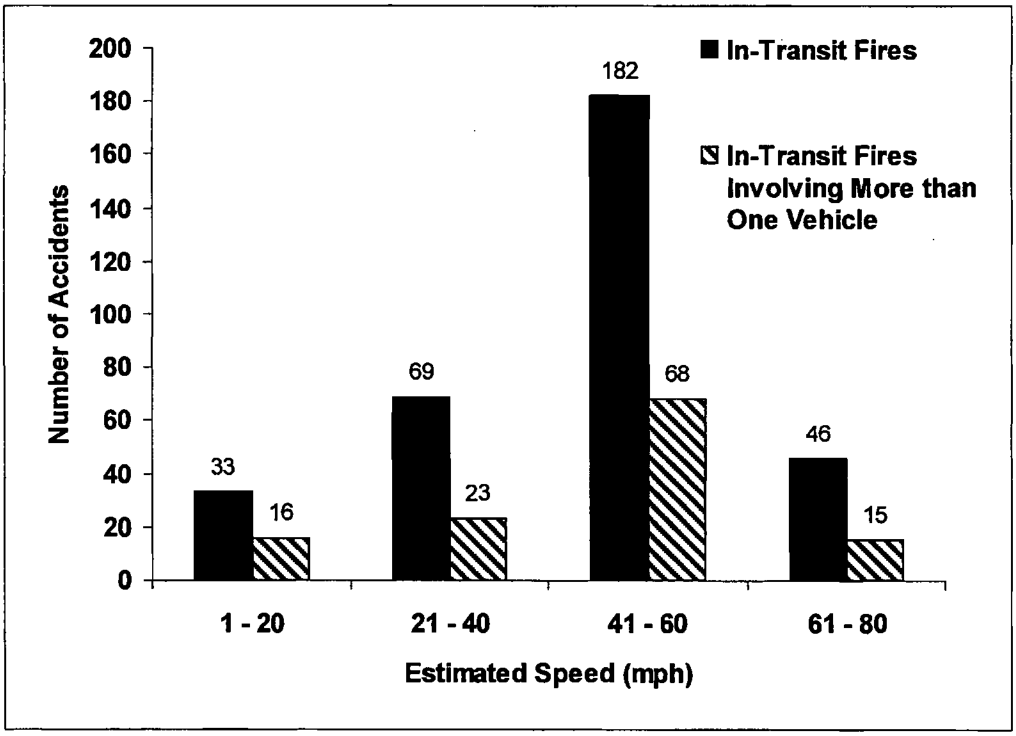

Figure 2-5. Estimated Speed for In-Transit Fires. To Convert mph to km/h, Multiply by 1.609.

Table 2-3. In-Transit Fires Involving More Than One Vehicle and a Flammable Liquid Release

Speed Range (mph)*	Number of In-Transit Fires	Average Amount of Flammable Liquid Released (gal)†	Maximum Amount of Flammable Liquid Released (gal)†
1 to 20	9	3,653	10,000
21 to 40	19	5,225	8,803
41 to 60	49	4,918	13,400
61 to 80	10	5,038	8,900

*To convert mph to km/h, multiply by 1.609.
†To convert gal to L, multiply by 3.785.

Although not shown in Figure 2-5, 6 of the 330 in-transit fires occurred at estimated speeds greater than 113 km/h [70 mph] with 3 of these accidents involving more than 1 vehicle. The description for one accident occurring on April 24, 2006, in Spanish Fork, Utah, identified that the vehicle was traveling too fast. It was traveling at an estimated speed of 121 km/h [75 mph].[2] However, in other cases such as those involving single-vehicle rollovers, accident descriptions referred to the vehicle entering a curve too fast or traveling too fast for the road conditions. For example, the recommendations involving one accident occurring on April 20, 2005, in Golconda, Nevada, identified that the driver entered the curve too fast. The estimated speed for this accident was 56 km/h [35 mph].[3]

Table 2-3 summarizes in-transit fires involving more than one vehicle where flammable liquid was also released. This table shows the average amount of flammable liquid released in these fires in terms of the estimated speed for the vehicle carrying HAZMAT. As shown in this table, 87 in-transit fires were identified over the 4 speed ranges from 1.6 to 129 km/h [1 to 80 mph] with a release of flammable liquid. For the higher 3 speed ranges, the average amount of flammable liquid released was just above or just below 18,925 L [5,000 gal]. At the lower speed range from 1.6 to 32 km/h [1 to 20 mph], fewer than 15,140 L [4,000 gal] of flammable liquid, on average, were released. Although not shown in the table, for the speed range from 66 to 97 km/h [41 to 60 mph], about half of the fires (i.e., 26 out of 49) involved a release of more than 22,710 L [6,000 gal] of flammable liquid. Similarly, in the highest speed range from 98 to 129 km/h [61 to 80 mph], half of the fires (i.e., 5 out of 10) involved a release of more than 22,710 L [6,000 gal] of flammable liquid.

Table 2-3 also shows the maximum amount of flammable liquid released for each of the four speed ranges. As shown in this table, the maximum amount of flammable liquid released exceeded 22,710 L [6,000 gal] in all 4 speed ranges with the highest release occurring in the speed range from 66–97 km/h [41–60 mph]. This speed range also showed the greatest number of in-transit fires.

[2]For more information on this accident, refer to PHMSA (2010b, Report Number E–2006100009).
[3]For more information on this accident, refer to PHMSA (2010b, Report Number E–2005040296).

3 IDENTIFICATION OF SEVERE FIRE ACCIDENTS

This section identifies roadway fires that had the greatest potential to exceed the bounds of the HAC fire described in 10 CFR 71.73(4). These criteria are established in 10 CFR 71.73(4) and, in essence, require a transportation package to be designed to survive a fully engulfing fire with an average flame temperature of not less than 800°C [1,475°F] for a period of not less than 30 minutes. When subjected to the HAC fire, the transportation package must maintain containment, shielding, and criticality functions through and after the fire exposure. However, when evaluating actual historical roadway accidents, as reported in the PHMSA database, a quantitative identification of a fully engulfing fire, with similar characteristics as the one described in 10 CFR 71.73(4), can present some difficulties. Accident data for roadways are often in summary form, and the records are not focused on the exact fire durations, temperatures experienced, and magnitudes for these accidents. This makes it challenging to characterize a fire resulting from a roadway accident as having the potential to (i) fully engulf a transportation package or (ii) produce a thermal environment similar to the one described in 10 CFR 71.73.

In lieu of quantitative identification of fully engulfing fires, this chapter attempts to identify historic roadway fires that had a reasonable potential to approach or exceed the bounds of the HAC fire described in 10 CFR 71.73(4). These fires are herein referred to as severe fires. Because of the lack and inconsistency of data for each roadway fire, various criteria were used to define a severe fire, but not all could be applied to each accident identified in Chapter 2.

- The first criterion was that the principal source of fuel for the substantially engulfing fire must have been derived from another vehicle. The purpose of this first criterion was to (i) restrict the term "severe fires" to those fires that could have affected an SNF package (implicitly assuming the SNF package does not provide fuel to the fire) and (ii) exclude roadway accidents where the fire only involved the one vehicle (i.e., the vehicle where the fire originated). This first criterion was partially evaluated in Chapter 2 by examining only those accidents involving a collision or potential collision with multiple vehicles. If a collision did not occur, then there is very little chance of the fire involving multiple vehicles.
- The second criterion was that the flammable material involved had to be a liquid, which could potentially pool underneath an SNF transportation package.
- The third criterion was that the accident was between two or more automobiles and did not include an accident between a train and an automobile. This criterion is similar to the first because it assumes that the conveyance on which the SNF package is being transported does not provide fuel to the fire, and an accident between a transportation package and train would not be expected to lead to a severe fire fully engulfing the package. This also assumes that the train's flammable material would not lead to a pooling fire below the material package. This assumption seems reasonable because a review of the accidents involving trains indicates that most of the fires initiated from the truck carrying HAZMAT.
- The final criterion that was used to evaluate the severity of these fires is that the fire must persist for a considerable time to effectively transfer the heat to the canister/container carrying nuclear materials. Thus, under the constraints of this definition, a roadway accident that can be considered a severe fire is one that lasted for an extended period of time and could have engulfed an SNF transportation package.

These criteria defining a severe fire contain some subjective elements (criterion one: "substantially engulfing" and "principal source of fuel"; criterion four: "extended period of time").

These subjective elements are a result of the information or descriptions provided in many of the accident reports. Most of the information provided in the PHMSA data or National Transportation Safety Board (NTSB) reports focuses on identifying the causes and determining preventative actions to reduce these types of accidents from occurring in the future. While this reporting is highly beneficial to society, the reports often do not provide much, if any, specific information about the ensuing fires. Damages are assessed in terms of the lost freight, equipment, and life. Additionally, if emergency response information is included, it is often with regard to how the fires were contained and does not necessarily detail the efforts used to contain the fires. Without these detailed assessments, the evaluation of roadway accidents often relies on the interpretation of sparse information and details contained in accident photographs. These photographs, in conjunction with the accident description (where available), provide information on the number of vehicles involved in the fire. However, the evaluation of an event could have been altered by the timing or angle of the photograph.

Because of the minimal amount of information, the use of the PHMSA roadway report descriptions as a basis to classify roadway accidents often requires the use of inference, which potentially could be interpreted as subjective. A general guideline used in this analysis follows:

- "Substantially engulfed" was interpreted as a fire that could have pooled below and engulfed at least 30 percent of the surface area of a transportation package.
- "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. Most of the accident descriptions did not provide information on the fire duration. As such, assumptions were made based on the amount of fuel that was burned in the fire. A study by Blinov and Khudiakov (1961) determined that for diesel pool fires, the regression rate reaches a steady state of roughly 4 mm [0.2 in] per minute when the diesel pool fire has a surface area larger than 1.76 m^2 [19 ft^2]. Assuming that a transportation package for nuclear materials is roughly 5 m [16 ft] long with a 1-m [3-ft] diameter {based on LWT package in NUREG–0383, "Directory of Certificates of Compliance for Radioactive Materials Packages" (NRC, 2009)} and the fire is on one side of the package, 30 percent of the surface area would be engulfed by a fire having a footprint of roughly 1.6 m^2 [17 ft^2] {i.e., a rectangular area of 1.6 m × 1 m [5.2 ft × 3 ft]}. Therefore, to have a fire last longer than 30 minutes, the fuel would need to have a minimum depth of 0.12 m [0.39 ft], which leads to a minimum volume of liquid of 212 L [56 gal]. Consequently, we can reasonably assume that if the volume of liquid was less than roughly 212 L [56 gal], it would not lead to an extended fire. However the physics of an unconfined spill are such that fuel depths and constrained area assumptions in this analysis are conservative. A pool fire condition typically requires several hundreds of gallons of diesel fuel to complete a 30-minute fire exposure (e.g., based on requirements from 10 CFR Part 71.73). The volume of 56 gallons was selected to establish a minimum fuel quantity for the purpose of classifications in this study.

3.1 Roadway Accidents Involved in Potential Severe Fires

During the last 12 years (i.e., 1997 to 2008), more than 23,000 reportable in-transit roadway accidents occurred involving HAZMAT (Table 2-1), and of all these accidents, only a small percentage has been indentified as having potentially severe fires. The process of identifying those accidents with severe fires began by identifying and focusing on those accidents involving a fire. As described in Section 2.3, this criterion reduced the number of candidate accidents to just 477 in-transit accidents involving HAZMAT and a fire. The next criterion used was to examine only those accidents that involved a collision or potential for collision. This criterion reduced the number of accidents to 140 as shown in Table 2-1.

This section (i) identifies those events that involved severe fires and (ii) identifies trends that could help identify severe fire accidents. These results can then be used to focus attention on those historic events that were more likely to have challenged the thermal safety criteria for shipping SNF transportation packages and to identify any trends in these accidents that could be used to better understand the risks involved in SNF roadway transport.

The 140 roadway accidents identified as having the potential for a severe fire were initially identified through a search of the PHMSA accident database of roadway accidents involving HAZMAT for the period between 1997 and 2008. After these accidents were identified, details about these accidents were then derived from the PHMSA accident data summary information, NTSB reports, and online news outlets. However, of the 140 accidents initially identified, 49 accidents did not have enough information to determine their severity. Consequently, these events were not evaluated to determine the fire severity, nor were they included in the severe accident parameter trend analysis in Section 3.4. These excluded roadway accidents are included in Appendix A.

Of the 140 initially identified accidents, enough information was provided in the PHMSA report, NTSB reports, and/or new agency information for 91 accidents to determine whether the accidents led to severe fires. These 91 accidents with their location and dates are listed in Appendix B.

3.2 Brief Description of Roadway Accidents

The evaluated accidents are briefly described next. These accidents have been grouped according to their classification as including or not including a severe fire. Those determined not to be a severe fire have been grouped by how their severity was determined. Most of the data, as indicated earlier, were obtained from the PHMSA database; however, for some accidents, information was available from other sources. These sources are referenced along with the data. Where there are no additional references, the PHMSA database was the only source of information.

3.2.1 Accidents With No Severe Fire

As previously discussed, the accidents identified in Appendix B had enough information to determine the severity of the fire. One of the first screening mechanisms used was the elimination of any accidents that were between vehicles and a train (if the vehicle was a transportation package and it was struck by a train, this would not be expected to lead to a severe fire, as discussed previously). Of all the 91 accidents in Appendix B, 9 accidents involved a collision between a HAZMAT vehicle and a train. These accidents are described in Table 3-1.

Table 3-1. Roadway Accidents Involving a Collision With a Train

Date	Location	Material Released
February 19, 2007	Falkville, Alabama	6.8 m^3 [240 ft^3] of propane
March 26, 1007	Glendora, Mississippi	23,204 L [6,130 gal] of diesel fuel
January 20, 2006	Lagrange, Texas	25,915 L [6,846 gal] of natural gas
June 25, 2004	Chalmette, Louisiana	31,801 L [8,401 gal] of gasoline
August 1, 2002	Clear Lake, Iowa	Fuel oil
December 13, 2001	Gary, Indiana	1,066 kg [2,350 lb] of calcium carbide
February 21, 2000	Henderson, Kentucky	0.37854 m^3 [13.368 ft^3] of acetylene
September 12, 2000	Sandersville, Georgia	568 L [150 gal] of fuel oil
October 26, 2000	Aguilares, Texas	28,936 L [7,644 gal] of crude oil

Another previously discussed criterion to determine whether an accident could have been a severe fire was based on the type of fuel released. For a fire to have been considered severe, it was assumed that the fuel released would have been able to pool under the transportation package. While most of the materials involved in the fire occurred in a liquid state, 10 accidents involved flammable gases and 2 accidents involved flammable material being burnt while released from a tank's pressure relief valve. These events are highlighted in Table 3-2.

Table 3-2. Roadway Accidents Involving Material That Could Not Pool

Date	Location	Material Released
December 23, 2004	San Antonio, Texas	35,159 L [9,288 gal] of propane
August 6, 2004	Maybell, Colorado	Propane vapors
September 16, 2002	Massey, Maryland	63 m^3 [2,230 ft^3] of hydrogen
May 18, 2001	Detroit, Michigan	Only nitrogen refrigerant was lost from venting
May 1, 2001	Ramona, Oklahoma	4,078 m^3 [144,000 ft^3] of hydrogen*
December 28, 2000	Fort Lauderdale, Florida	3,028 L [800 gal] of gasoline was burned while venting from pressure relief value (not enough material to pool)
February 17, 2000	Rolla, Missouri	Propane
June 28,1999	Bruceville, Texas	Propane
November 2, 1998	Government Camp, Oregon	5,300 L [1,400 gal] of petroleum gas
October 5, 1998	Woburn, Massachusetts	Methane
August 11, 1997	Painter, Virginia	3,407 L [900 gal] of propane
June 26, 1997	Columbus, Ohio	Carbon dioxide

*NTSB. "Animations Simulating the Collision and Fire of Tractor/Cargo Tank Semitrailer and Passenger Vehicle, Yonkers, New York, October 9, 1997." 2010. <http://www.ntsb.gov/Events/yonders/anim_desc.htm> (April 2010).

The third criterion used for screening was the amount of material released during the accident. As indicated previously in this chapter, 212 L [56 gal] of liquid fuel were calculated as the minimum amount of material that would need to be released to engulf one-third of a transportation package for longer than 30 minutes. Based on this information, 20 of the accidents did not have enough material to result in a long duration fire. This was determined by examining the amount of material reported released in the PHMSA accident report. A list of these accidents and the basis for not considering the accidents severe is provided in Table 3-3. For all of the accidents in Table 3-3, the maximum amount of HAZMAT that was released was 208 L [55 gal] of gasoline.

Table 3-3. Roadway Accidents With Insufficient Material Release To Be Severe

Date	Location	Material Released
June 30, 2008	Princeton, Minnesota	76 L [20 gal] of gasoline
July 18, 2008	Prairie City, Iowa	No release
October 18, 2006	Macon, Georgia	11.8 L [3.125 gal] of butane
November 3, 2004	Snow Hill, Maryland	30 L [8 gal] of methyl ethyl ketone
August 13, 2004	Berrien, Michigan	No release indicated in description
August 3, 2004	Defiance, Ohio	No release
May 14, 2004	Cranbury, New Jersey	0.95 L [0.25 gal] of medical waste
October 1, 2003	Mission Viejo, California	76 L [20 gal] of gasoline
February 17, 2002	Santa Rosa, California	No release indicated in description
December 4, 2001	Bakersfield, California	57 L [15 gal] of crude oil
November 29, 2001	Canton, Michigan	38 L [10 gal] of gasoline
November 23, 2001	Honea Path, South Carolina	16.0 L [4.23 gal] of fuel oil
October 23, 2001	Braselton, Georgia	167 L [44 gal] of paint
July 11, 2001	Detroit, Michigan	208 L [55 gal] of gasoline
February 26, 2001	Springfield, Massachusetts	15 L [4 gal] of gasoline
August 2, 2000	Altoona, Pennsylvania	189 L [50 gal] of gasoline
November 22, 1999	Hammond, Indiana	No release indicated in description
November 12, 1999	Hammond, Indiana	76 L [20 gal] of gasoline
February 15, 1998	Wilmington, Delaware	76 L [20 gal] of gasoline
April 25, 1997	Jacksonville, Florida	14.20 L [3.75 gal] of acetone, 6.151 L [1.625 gal] of alcohol, and 18.45 L [4.875 gal] of turpentine

The final method to screen the accidents as not severe was by examining the number of vehicles involved in the fire. The accident descriptions were reviewed to determine whether, after the collision, multiple vehicles were engulfed in the fire. If only a single vehicle was engulfed in the fire, the accident was deemed to be not severe (if a transportation package had been involved, it was assumed not to be the source of the fire, and would have had to be engulfed by a fire that originated from another vehicle). Accidents screened as having only a single vehicle involved in the fire are listed in Table 3-4. In Table 3-4, there are 27 accidents where the fire only involved the vehicle releasing the HAZMAT.

Table 3-4. Roadway Accidents With Fires Involving a Single Vehicle

Date	Location	Description of Fire
April 26, 2008	High Springs, Florida	A tractor-trailer was hit head-on by another tractor-trailer, which led to the fire. The second truck overturned but did not catch fire.
May 10, 2007	Howell Township, New Jersey	A tanker truck was hit broadside by another vehicle. The second vehicle careened across the grassy median but was not burnt in the fire.*
December 15, 2006	Pittsburg, Kansas	A vehicle crossed the center lane and hit a vehicle containing HAZMAT but was not involved in the fire.
August 12, 2006	Lawton, Oklahoma	A tanker truck failed to clear a vehicle while passing, which caused the tanker to end up in the middle of the roadway and the other vehicle on side of the road in a ditch.
April 15, 2006	Purchase, New York	A tractor-trailer swerved to avoid a disabled vehicle, which made it hit the cement barrier, igniting the trailer.
July 12, 2005	Ridgefield, Connecticut	A tanker truck was cut off by another vehicle. In the process of avoiding the vehicle, the tanker jackknifed and ignited, while the other vehicle left the scene.†
June 29, 2005	Kern, Colorado	A tanker truck going downhill lost use of its brakes, hitting another tractor-trailer from behind. The tanker safely pulled to side of the road, and the tractor-trailer was discovered to be on fire.
April 5, 2005	London, Kentucky	A tractor-trailer hit another vehicle that had lost control. This led to the tractor-trailer overturning and continuing over an earth embankment where only it was engulfed in a fire.
April 17, 2004	Greenville, North Carolina	A passenger vehicle collided with a tanker truck and resulted in the tanker burning in the fire.
March 25, 2004	Bridgeport, Connecticut	A passenger vehicle struck a tanker truck that caught on fire. The passenger vehicle was not involved in the fire.‡
March 20, 2004	Waco, Texas	A tow truck was towing a tanker truck when it was hit by another vehicle. Both the tow truck and the tanker being towed were burned in the gasoline fire.

Table 3-4. Roadway Accidents With Fires Involving a Single Vehicle (continued)		
Date	Location	Description of Fire
October 19, 2003	Phoenix, Arizona	A tanker truck was hit by another vehicle, which led to the overturn and fire on the tanker truck. The other vehicle went through a fence off the freeway.
September 23, 2003	Bell Gardens, California	A tanker truck swerved to avoid an abandoned vehicle left in the freeway lane, which caused the tanker to roll over, leading to a fire that did not involve the second vehicle.§
July 24, 2003	Birmingham, Alabama	A tanker truck entering an intersection avoided hitting a vehicle that turned in front of the tanker, which resulted in the tanker turning over.
June 9, 2001	Atlanta, Georgia	A tanker truck hit a disabled vehicle that was left in the roadway. This lead to the tanker truck rolling over and down the highway and igniting.
May 20, 2001	Carson, California	A tractor-trailer was hit by passenger vehicles, sending it into the shoulder of the roadway and rolling over an embankment onto an on-ramp to the freeway.
November 4, 2000	Centerville, Utah	A tanker truck was cut off leading to the tank igniting. The tanker truck was able to avoid other vehicles.
June 8, 2000	Alvwood, Minnesota	A tanker truck hit a boat trailer coming onto the highway, which led to the trailer going off the road and down an embankment.
June 6, 2000	Carnesville, Georgia	A tanker truck swerved to miss another vehicle that had crossed the center line. There was no contact between the two vehicles.
March 15, 2000	Ellsworth, Wisconsin	A tanker truck pulled off the road to avoid a vehicle that had crossed the center lane. While coming back onto the road, the tanker truck overturned, causing the fire.
October 23, 1999	Irving, Texas	A tanker truck was struck by a vehicle that had crossed the center median. After the impact, the tanker continued down the road, hitting a guardrail and then a bridge abutment. The cargo tank was punctured, which led to the fire.
September 20, 1999	Pleasant View, Tennessee	A tanker truck was hit by a personal vehicle, which led to a fire and loss of the tanker truck and trailer.
August 11, 1999	Dawson Springs, Kentucky	A tractor truck rear-ended another vehicle. The tractor truck veered off the road into the median and overturned, causing the fire. The fire only consumed the tractor.
August 3, 1999	Mitchell, South Dakota	A tanker truck hit another vehicle, causing damage to the tanker's front right tire. The tanker pulled to the side of the road, and it was then noticed that the tanker was on fire.

Table 3-4. Roadway Accidents With Fires Involving a Single Vehicle (continued)		
Date	**Location**	**Description of Fire**
September 5, 1997	Brownsburg, Indiana	A tanker truck swerved to avoid another vehicle that had crossed the center line. The tanker truck dropped off the edge of the pavement, and the vehicle rolled onto its side and caught fire.
July 25, 1997	Bloomington, Illinois	A tanker truck was cut off and hit a passenger vehicle from behind, which made the tanker jackknife. The tanker rolled onto its side and down into a ditch where it caught fire and burned.
February 21, 1997	Marshall, Illinois	A tanker truck was struck from behind by another truck. This accident led to the rupture of the tanker's vehicle, which caught fire. The fire department arrived on the scene quickly enough to prevent the other truck's cargo from igniting.

*Appezzato, J. "Driver of Tanker Truck Killed in Fiery Route 195 Crash." 2007. <http://blog.nj.com/ledgerupdates/2007/05/driver_of_tanker_truck_killed.html> (7 April 2010).
†NRWA. "Devastating Truck Accident Kills Driver and Impacts Bridge and Norwalk River in Ridgefield, Connecticut." 2010. <http://www.norwalkriver.org/accident.htm> (7 April 2010).
‡Associated Press. "Fiery Crash Shuts I-95 Section in Conn." 2004. <http://www.urbanplanet.org/forums/index.php?/topic/3161-i-95-crash-and-aftermath/> (7 April 2010).
§Los Angeles Times. "Tanker Truck Blast Kills Driver, Forces Evacuations." 2003. <http://articles.latimes.com/2003/sep/24/local/me-explode24> (7 April 2010).

3.2.2 Accidents With Severe Fires

Twenty-three accidents out of the original 140 were considered to be severe. These accidents and their descriptions are listed in Table 3-5.

Table 3-5. Roadway Severe Accidents		
Date	**Location**	**Description of Fire**
October 5, 2008	Chattanooga, Tennessee	An empty tanker truck rear-ended another tractor-trailer, which led to the tractor catching on fire.
July 5, 2008	Kingman, Arizona	A tractor-trailer collided with the rear of a tanker truck, resulting in the release of gasoline and subsequent fire. Multiple vehicles were involved in this accident.*
March 28, 2008	Chicopee, Massachusetts	A tanker truck was struck by a passenger vehicle resulting in the tanker rolling over and igniting. The diesel fuel consumed at least three vehicles in the fire.†
March 24, 2008	Lower Makefield, Pennsylvania	A dump truck collided with a tanker releasing 4,542 L [1,200 gal] of fuel oil. The dump truck and a passenger vehicle were engulfed in the fire.‡
November, 7, 2007	Tallulah, Louisiana	A tractor-trailer lost control after hitting another vehicle. The tractor-trailer crossed the median and struck another vehicle, which resulted in a fire consuming both vehicles.
June 23, 2007	Harrisburg, Pennsylvania	A tractor-trailer hit a stopped vehicle on the highway, causing a fire that engulfed five vehicles including the tractor cab.§
March 14, 2007	Picacho, Arizona	A passenger vehicle became wedged below a tractor-trailer and was dragged, which initiated a fire engulfing both vehicles.
April 21, 2006	Dahlonega, Georgia	A tanker truck was turning into a gas station when a passenger vehicle struck the tanker. Both the vehicle and tanker were caught in the fire.
July 28, 2005	Kingsport, Tennessee	A tractor-trailer moved into oncoming traffic from the emergency lane. A second tractor-trailer hit the vehicle coming into the moving lanes. The second tractor-trailer overturned onto a pickup truck, which led to a fire engulfing both the tractor-trailer and pickup truck.‖
May 11, 2005	Berks, Pennsylvania	A tractor-trailer rear-ended a tanker truck, which ripped open both units. Explosive dust from the tractor-trailer exploded, catching both units on fire.
September 13, 2004	Carlos, Texas	A tanker truck collided with another vehicle that had crossed the centerline of the road. The tanker truck rolled off the road. A third vehicle was forced off the road near the tanker truck. Though not in the fire, the third vehicle sustained extensive body damage due to the heat from the fire.

Table 3-5. Roadway Severe Accidents (continued)		
Date	Location	Description of Fire
March 13, 2004	Taylor, Michigan	A tanker truck was struck by another vehicle going through a red light, which resulted in a fire. The fire engulfed the tractor and the other vehicle.
January 13, 2004	Elk Ridge, Maryland	A tanker truck lost control and went over an overpass, landing across lanes of the highway and causing a fire. Other than the tanker truck, three trucks and two passenger vehicles were involved in the fire.
December 14, 2003	Greenville, Tennessee	A vehicle traveling the wrong direction hit the tanker truck, causing a fire that consumed both vehicles.
May 18, 2003	Ovilla, Texas	A multivehicle accident led to a fire, which involved four vehicles.
November 29, 2001	Canton, Michigan	A tanker truck was hit by a passenger vehicle that crossed into the wrong lanes of traffic. The vehicle caught on fire, which ignited the tanker truck. Both vehicles were engulfed in the fire.
April 2, 2001	Green Bay, Wisconsin	A tanker truck was making a turn at an intersection when another vehicle failed to stop at the stop sign and struck the tanker. The accident caused an immediate fire, which engulfed both the passenger vehicle and tanker.
October 25, 2000	Mill Creek, Ohio	A tanker truck, trying to avoid collision with stopped vehicles, moved into an oncoming lane where another tractor-trailer was located. The second tractor-trailer attempted to avoid the tanker and lost its cargo, which punctured the tanker. The second trailer hit the tanker, and both were consumed in the subsequent fire.
January 25, 1999	Davie, Florida	A tanker truck was entering a highway when it lost control and pulled two other vehicles into the median. The tanker ruptured and burst into flames, engulfing all three vehicles.
December 18, 1998	Raleigh, North Carolina	A tanker truck struck an abandoned pickup truck that was in the travel lanes. This led to the fire that engulfed both vehicles.
October 17, 1998	Huntsville, Alabama	A tanker truck struck an abandoned pickup truck and traveled down a steep embankment. Upon striking the bottom of the embankment, the vehicle caught fire. Two parked vehicles located near the fire were affected by the fire.
July 7, 1998	Mustang, Oklahoma	A tanker truck entering an intersection was hit by a passenger vehicle that ran a red light. Both the passenger vehicle and tanker truck caught on fire immediately.

Table 3-5. Roadway Severe Accidents (continued)

Date	Location	Description of Fire
October 9, 1997	Yonkers, New York	A tanker truck turning onto a road was broadsided by a passenger vehicle, which led to a fire that engulfed both vehicles.¶

*CNN. "Dispatch Audio from Major Tanker Fire on US 68 Near Kingman LIVE." 2008. <http://www.ireport.com/docs/DOC-42978> (7 April 2010).

†Buckley, M.R.F. "Fuel Tanker Crash Sparks Explosion, Fire." 2008. <http://www.thebostonchannel.com/news/15731400/detail.html> (7 April 2010).

‡Rawlins, J. "Oil Tanker Explodes in Collision." 2008. <http://abclocal.go.com/wpvi/story?section=news/local&id=6038282> (7 April 2010).

§Monek, B. "Pa. Turnpike Accident Kills 3 People." 2007. <http://abclocal.go.com/wpvi/story?section=news/local&id=5415318> (7 April 2010).

‖Breeding, K. "Driver Convicted of Criminally Negligent Homicide in I-81 Crash." 2009. <http://www.timesnews.net/article.php?id=9015658> (7 April 2010).

¶NTSB. "Animations Simulating the Collision and Fire of Tractor/Cargo Tank Semitrailer and Passenger Vehicle, Yonkers, New York, October 9, 1997." 2010. <http://www.ntsb.gov/Events/yonkers/anim_desc.htm > (7 April 2010).

3.2.3 Other Noteworthy Events

In addition to those accidents that released HAZMAT and where the fire involved two or more vehicles, special attention was given to those accidents located in an enclosed space (e.g., overpass or tunnel). Studies have shown that fires in an enclosed space can lead to higher temperatures (Lönnermark and Ingason, 2005). An example is an enclosed accident that occurred in an Oakland, California, tunnel in 1982 between a bus and a tanker truck. The fire that occurred in the Caldecott Tunnel achieved temperatures as high as 1,025 °C [1,877 °F] as evidenced by the incinerated materials (Larson, et al., 1983). As such, some accidents where only single vehicles were exposed to the fire were also examined to determine whether these accidents occurred in an enclosed environment because the temperatures in an enclosed environment could still potentially affect a transportation package even if the package was not fully engulfed in the fire. For this report, an enclosed location was taken as either under a bridge or overpass, or in a tunnel. Accidents determined to be in an enclosed area are listed in Table 3-6. Note that the first six accidents listed in Table 3-6 under, "Accidents Where Multiple Vehicles Were Involved in the Fire" were accidents included in the evaluation described in Sections 3.2.1 and 3.2.2. Out of these six accidents, only the Elk Ridge accident was determined to be a severe fire. The other accidents in this table listed under "Other Accidents" were accidents identified as being in an enclosed space, but these did not involve either HAZMAT or multiple vehicles.

Table 3-6. Roadway Accidents in Enclosed Space

Accidents Where Multiple Vehicles Were Involved in the Fire	
Date	**Location**
May 28, 2005	Irving, Texas
January 13, 2004	Elk Ridge, Maryland
January 5, 2002	Birmingham, Alabama
June 9, 2001	Atlanta, Georgia
October 23, 1999	Irving, Texas
Other Accidents	
Date	**Location**
September 28, 2008	New Virginia, Iowa
June 10, 2008	Baltimore, Maryland
October 12, 2007	Santa Clarita, California
April 29, 2007	Oakland, California
June 9, 2005	Chicago, Illinois
January 1, 2002	Birmingham, Alabama
December 28, 2001	Tampa, Florida
Other Accidents	
Date	**Location**
October 24, 2000	Forth Worth, Texas
July 20, 2000	Warwick Rhode Island
May 27, 2000	Detroit, Michigan
October 7, 1997	Sacramento, California

3.3 Frequency of Severe Roadway Accidents

Table 3-7 includes the roadway accidents releasing HAZMAT that occurred in the last 12 years involving a severe fire as described in Section 3.2. For the 140 roadway accidents that could have or did include a collision, the fire was severe in roughly 17 percent (i.e., 23 out of 140 accidents). As shown in Table 3-7, on average for the last 12 years, there were 2 severe fires accidents per year with an overall frequency of roughly 4.90×10^{-5} accidents per million HAZMAT vehicle-km [7.89×10^{-5} accidents per million HAZMAT vehicle-mi].

Table 3-7. Summary of Severe Roadway Accidents From 1997 to 2008

Year	Million HAZMAT Miles*	Severe Fire Incidents	Frequency†
1997	24,788	1	4.03×10^{-5}
1998	23,400	3	1.28×10^{-4}
1999	24,152	1	4.14×10^{-5}
2000	24,489	1	4.08×10^{-5}
2001	24,908	2	8.03×10^{-5}
2002	23,362	0	0
2003	23,723	2	8.43×10^{-5}
2004	24,038	3	1.25×10^{-4}
2005	24,224	2	8.26×10^{-5}
2006	24,223	1	4.13×10^{-5}
2007	24,707	3	1.21×10^{-4}
2008	24,707	4	1.62×10^{-4}
Total	**291,566**	**23**	**7.89×10^{-5}‡**

*To convert to kilometers, multiply miles by 1.609.
†Frequency in accidents per million HAZMAT vehicle-mi. To convert to accidents per million HAZMAT vehicle-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 5.00×10^{-5} accidents per million HAZMAT vehicle-mi and the upper limit is 1.18×10^{-4} accidents per million HAZMAT vehicle-mi.

3.4 Severe Fire Accident Parameter Trends

Roadway accidents involving severe fires were analyzed to determine the trends associated with these accidents. The results of these analyses are shown in the following sections.

3.4.1 Hazardous Material Type and Quantity

Figure 3-1 shows roadway severe accident fires involving HAZMAT classes for flammable material, organic peroxide, poisons, corrosives, and miscellaneous materials. As shown in this figure, the majority of accidents determined to be severe contain flammable liquids. This is a reasonable conclusion because flammable liquid is the most likely material to create a pool that could potentially engulf a transportation package in the ensuing fire.

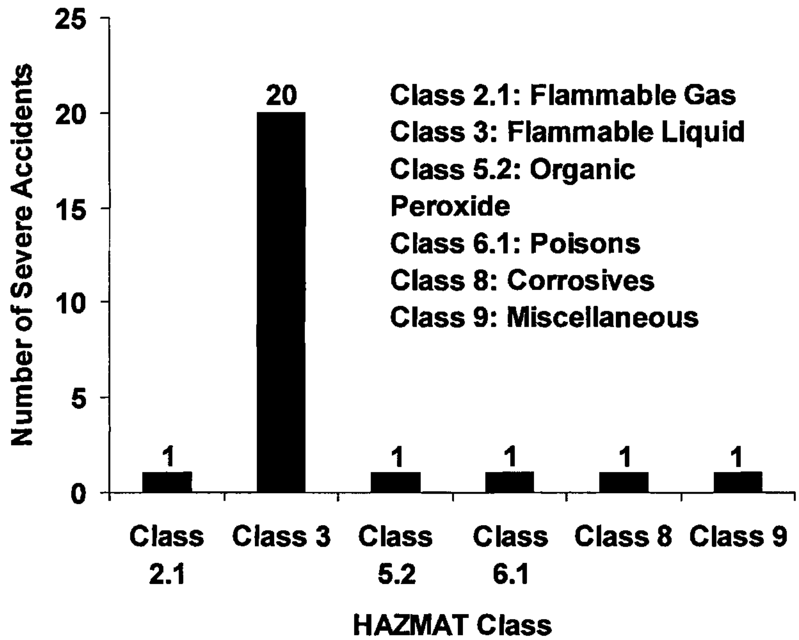

Figure 3-1. Severe Accidents Separated by Hazardous Material Class. Some Fires Involved More Than One Hazardous Material Class.

Figure 3-2 shows the amount of material that was released for the severe accidents containing liquid HAZMAT. In Figure 3-2, there appear to be two ranges of fuel release where severe fires occurred. The number of accidents that released fuel in the quantity range of 310 to 7,570 L [82 to 2,000 gal] is the same as accidents that released fuel in the range of 30,283 to 37,850 L [8,001 to 10,000 gal]. For the lower range, half of the accidents released 969 L [250 gal] or less, while the other half of the accidents released more than 3,100 L [800 gal] of fuel. For the upper range, the majority of the accidents released 33,713 L [8,700 gal] or more fuel. This result is interesting as it indicates that a severe fire does not have to be associated with a truck that has a complete load. Because any semi truck will typically contain two 757-L [200-gal] fuel saddle tanks, there is a potential for any large tractor-trailer to contain enough HAZMAT to engulf one-third of a transportation package for longer than the 30 minutes as discussed previously. However, as discussed previously, the physics of an unconfined spill are such that the fuel depths and constrained area assumptions are unknown and would affect the required amount of fuel necessary to maintain a fire for longer than 30 minutes.

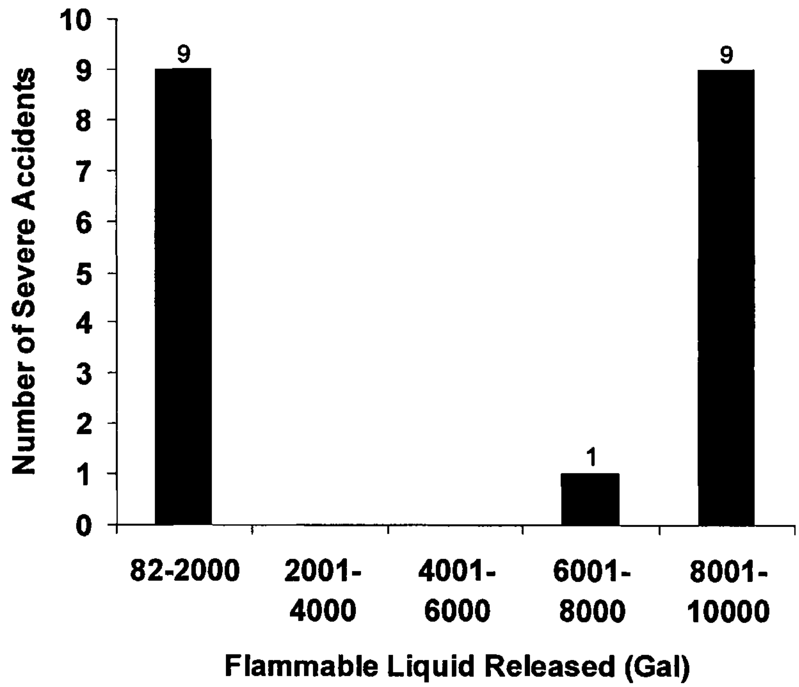

Figure 3-2. Amount of Flammable Liquid Released During Severe Accidents. To Convert From Gallons to Liters, Multiply by 3.785.

3.4.2 Speed and Time of Accident

Figure 3-3 shows the estimated speed of the vehicle containing HAZMAT when the severe accident occurred. The maximum number of severe accidents occurred during the 66–97 km/h [41–60 mph] speed, which is consistent with the maximum number of in-transit accidents with fires as shown in Figure 2-5. The number of accidents tapered off on either side of this range; another higher number of accidents occurred in the low speed range of 0 to 32 km/hr [0 to 20 mph]. These results show that the severe accidents appear to occur at high speeds (i.e., highway travel) or at lower speeds (e.g., turning in an intersection or while stopping on the highway).

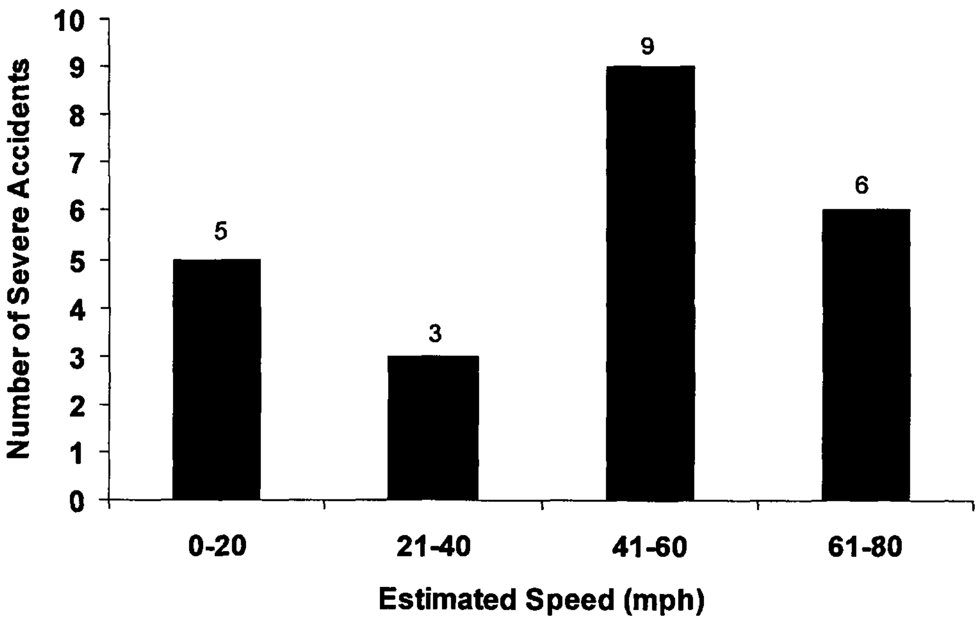

Figure 3-3. Estimated Speed for Severe Accidents. To Convert mph to km/h, Multiply by 1.609.

The times for the severe accidents are presented in Figure 3-4. This figure indicates that the severe accidents seemed to be dispersed evenly throughout the day. The more severe accidents occurred during the 6:00 a.m. to 12:00 p.m. time period, but there are only two additional accidents during this time period compared to the other periods.

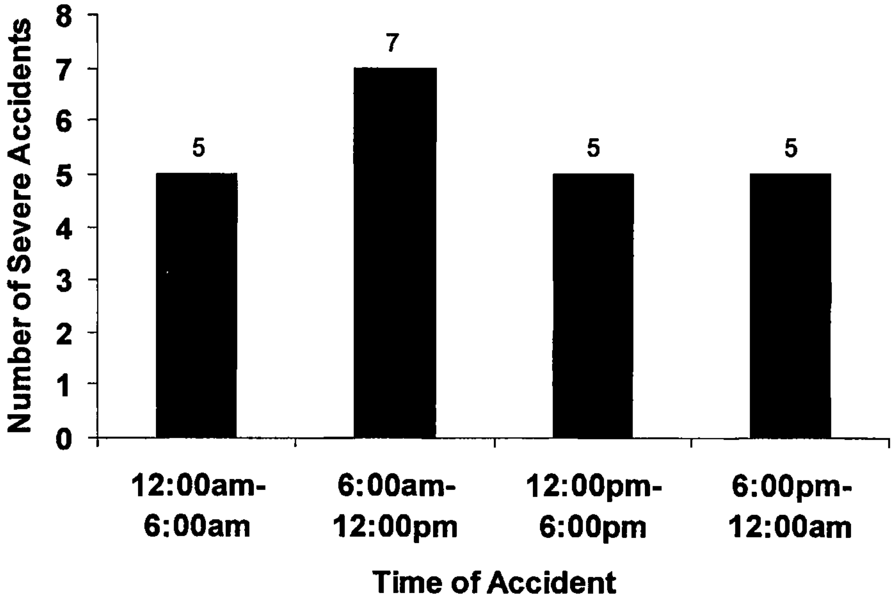

Figure 3-4. Time of Occurrence for Severe Accidents

3.4.3 Cause and Location of Severe Accident

The cause of the severe accidents was also examined to determine whether a trend could be identified. Various types of accidents appeared to occur more than once. This included a vehicle crossing the centerline of a road or median, a vehicle going through an intersection and hitting the HAZMAT vehicle, and the HAZMAT vehicle rear-ending or running into a stopped (e.g., stopped in traffic or abandoned on the highway) vehicle. Using these three categories and "other" for all the other types of accidents that occurred, the results have been presented in Figure 3-5. As can be seen, only 13 percent (3 out of the 23) of the severe accidents were from vehicles crossing the centerline of a road or median. Twenty-two percent (5 out of 23) of the severe accidents occurred in an intersection, while 26 percent (6 out of 23) of the severe accidents happened from the HAZMAT vehicle rear-ending a stopped vehicle. The remaining severe accidents were classified as "other." From these results, there does not appear to be an overwhelming cause for most of the severe accidents that occurred.

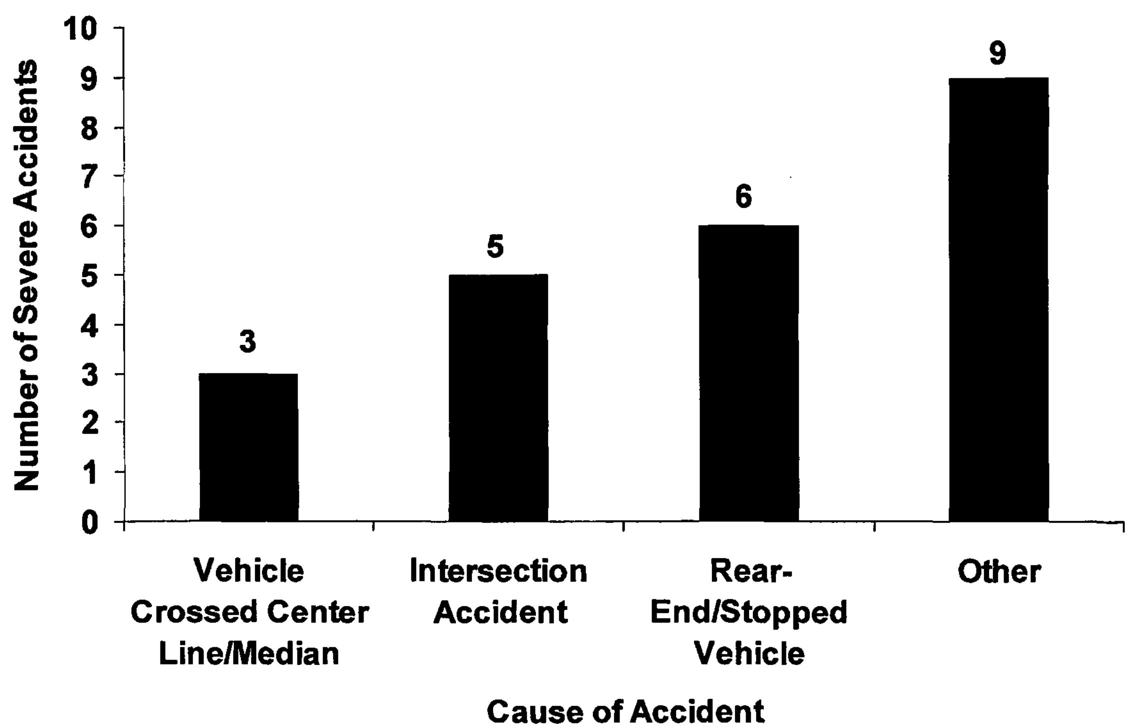

Figure 3-5. Cause of Severe Accidents

The location of severe accidents was also examined using the information provided in the PHMSA data reports. Figure 3-6 shows the locations of severe accidents separated into four classes. The first is interstates with a median or separated by a central dividing barrier. Forty nine percent (11 of the 23) of the severe accidents were located on this type of road. This seems a reasonable result because most HAZMAT travel would likely comprise interstate travel. Following interstates with a divide were accidents that occurred in an intersection, which comprised 26 percent of the locations (6 out of 23) for severe accidents. These were followed by roads with no dividers at 13 percent (3 out of 23) and interstate ramps at 9 percent (2 out of 23).

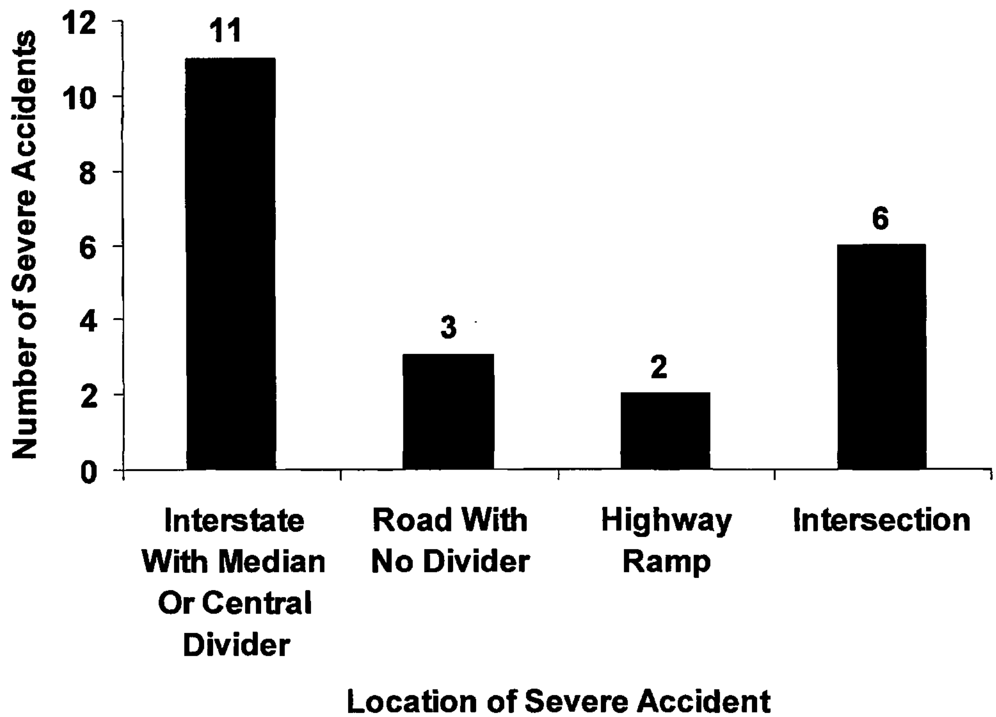

Figure 3-6. Location of Severe Accidents

As mentioned earlier, some special attention was given to those accidents located in or near an enclosed space. This is because a fire in an enclosed space will have a large heat contribution from radiation heat transfer. Therefore, a package in a fire near or in an enclosed space has the potential for achieving a higher temperature than one that is exposed to a fire in an open environment. Out of all the severe accidents, the accident that occurred at Elk Ridge, Maryland, on January 13, 2004, was likely in an enclosed space because of its location near a highway ramp. During this severe accident, the HAZMAT vehicle, which released 33,319 L [8,803 gal] of gasoline, lost control and went over an overpass onto another interstate, damaging multiple vehicles. While the ramp location represents a small fraction of the total number of severe accidents, an enclosed area such as this could lead to a more severe fire exposure.

3.4.4 Summary of Severe Fire Accident Parameter Trends

Four criteria were used to evaluate the 140 multicar accidents that were screened from the Chapter 2 analysis: (i) the principal source of fuel for the substantially engulfing fire must have been derived from another vehicle; (ii) the flammable material involved had to be a liquid, which could potentially pool underneath an SNF transportation package; (iii) the accident had to involve two vehicles and not a train; and (iv) the fire had to persist for an extended period of time. Using these 4 criteria, 23 accidents were identified as being severe.

The characteristics for these 23 accidents were examined to determine any important trends. From the data it was determined that severe roadway fire accidents are generally characterized by collisions between 2 or more vehicles in which HAZMAT was released with a quantity of more than 310 L [82 gal]. There did not seem to be many trends associated with these severe accidents, except that they mainly involved Class 3 HAZMAT. The amount of HAZMAT released varied from 568 to 35,961 L [150 to 9,500 gal]. The amount of fuel released in the severe accidents showed a bimodal histogram, with the majority of accidents releasing either 310 to 7,570 L [82 to 2,000 gal] or 30,283 to 37,850 L [8,001 to 10,000 gal] of fuel.

The vehicle speeds when the severe accident occurred were also examined. The severe accident speeds showed a slightly higher number of accidents occurring in the range from 66-97 km/h [41–60 mph]. However, this may be due to the number of vehicles that typically travel in this speed range. The number of accidents decreased moving away from this speed range, but then increased at the lower speed range of 0 to 32 km/h [0 to 20 mph].

The time and cause of the accidents were also investigated. The number of accidents was evenly distributed throughout the day, with a slightly higher rate between the 6:00 a.m. and 12:00 p.m. timeframe. Examining the cause of the accident, no singular accident type appears to occur more often. Finally, most accidents occurred on main interstates where there is a divider or median. However, this is likely due to the higher percentage of travel on these types of roads.

4 CONCLUSIONS

Based on the NAS recommendations, NRC is interested in determining the types and frequency of roadway accidents involving severe, long duration fires that could impact SNF transport on roadways. The results of this study suggest that in the previous 12 years (i.e., 1997 to 2008), more than 23,000 in-transit HAZMAT accidents occurred, resulting in a frequency of approximately 4.92×10^{-2} accidents per million HAZMAT vehicle-km [7.92×10^{-2} accidents per million HAZMAT vehicle-mi]. In addition, the number of in-transit HAZMAT accidents appears to have increased in the last 12 years from about 1,494 in 1997 to about 2,513 in 2008.

This study further examined the accident frequency associated with in-transit HAZMAT accidents resulting in a fire: 1.02×10^{-3} accidents per million HAZMAT vehicle-km [1.64×10^{-3} accidents per million HAZMAT vehicle-mi] and for those fires involving more than one vehicle, a frequency of approximately 2.98×10^{-4} accidents per million HAZMAT vehicle-km [4.8×10^{-4} accidents per million HAZMAT vehicle-mi].

The evaluation of fire-related accidents further identified those that were considered severe. Out of the 140 in-transit fires involving more than 1 vehicle, 23 were identified as severe based on the following criteria: (i) the principal source of fuel for the engulfing fire was from another vehicle, (ii) the fuel was flammable liquid that could pool under another vehicle, (iii) the accident involved more than one vehicle but not collisions of a vehicle with a train, and (iv) the fire persisted for an extended period of time. Based on these 4 criteria, about 2 severe fire accidents occurred per year resulting in a frequency of roughly 4.90×10^{-5} accidents per million HAZMAT vehicle-km [7.89×10^{-5} accidents per million HAZMAT vehicle-mi]. One of the 23 severe fires occurred on a freeway entrance/exit ramp, likely in an enclosed area. None of the 23 severe fires involved a release of radioactive material.

The accident frequencies estimated in this study are lower than the previous NRC and DOE studies of accident frequencies. because this report focuses on a much narrower data set : roadway accidents that involved a HAZMAT release, more than one vehicle, and resulted in a fire. The range of accident frequencies the previous NRC and DOE reports calculated was between 0.32 and 2.5 accidents per million vehicle-km [0.52 and 4.0 accidents per million vehicle-mi]. These values are orders of magnitude higher than the frequency calculated in this report for HAZMAT accidents involving a fire and more than 1 vehicle {i.e., 3.0×10^{-4} accidents per million HAZMAT vehicle-km [4.8×10^{-4} accidents per million HAZMAT vehicle-mi]} and the frequency calculated in this report for severe accidents {i.e., 4.90×10^{-5} accidents per million HAZMAT vehicle-km [7.89×10^{-5} accidents per million HAZMAT vehicle-mi]}.

In addition to calculating a frequency for severe accidents involving fire, accidents were analyzed to identify trends in the data. In general, severe fires are characterized by the release of flammable liquid (i.e., Class 3 HAZMAT), and in about 40 percent of the severe fires, more than 22,710 L [6,000 gal] of flammable liquid were released. Also, about half of the severe fires occurred on interstate highways with a median or divider and two of the severe fires occurred on interstate ramps. One of these accidents on a ramp was likely in an enclosed area and potentially led to a hotter fire. Consistent with their occurrence about half the time on interstate highways, typically more in-transit severe fires occurred in the range from 66 to 97 km/h [41 to 60 mph].

Out of more than 23,106 in-transit HAZMAT accidents, only about 2 percent (i.e., 477 out of 23,106) involved a fire and only about 0.1 percent (i.e., 23 out of 23,106) of the in-transit HAZMAT accidents resulted in a severe fire. In addition, only one of these in-transit severe fires likely occurred in a constrained environment. In summary, based on the analysis of roadway accident data involving in-transit HAZMAT fires, there is a very small frequency of a severe fire and therefore the likelihood that an SNF transportation package being transported on the roadway would be involved in a severe fire is also very small.

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APPENDIX A

This appendix lists and describes the roadway accidents that involved a fire and a collision that did not have sufficient information to determine whether a severe fire occurred.

Table A. Roadway Accidents With Insufficient Information To Determine Severity		
Date	Location	Summary
December 16, 2008	Ada, Oklahoma	A collision of a tractor truck with another vehicle punctures the tractor's fuel tanks, leading to a fire that consumed 787 L [200 gal] of diesel fuel.
December 4, 2008	North Little Rock, Arkansas	A tanker truck overturned and caught fire, releasing 33,327 L [8,804 gal] of gasoline.
August 23, 2007	West Point, Alabama	A tanker truck was hit at an intersection, leading to release of 17,034 L [4,500 gal] of gasoline and fire.
August 11, 2007	Junction, Texas	A tanker truck hit a parked construction truck, leading to release of 33,312 L [8,800 gal] of gasoline and fire.
August 1, 2007	Wheeler, Illinois	A tanker truck struck a tractor-trailer that caused the tanker to overturn and release 1,514 L [4,000 gal] of diesel fuel, which led to a fire.
July 29, 2007	Carryville, Tennessee	A tanker truck was hit by another vehicle that crossed the center lane, causing the tanker to overturn and release 32,206 L [8,508 gal] of gasoline, which led to a fire.
June 26, 2007	Strafford, Missouri	A tractor-trailer was involved in a multiple vehicle accident where 81 kg [180 lbs] of calcium hypochlorite was released.
July 19, 2006	Gowers Corner, Florida	A tanker truck was hit by another truck as it crossed the centerline of the road, releasing 30,283 L [8,000 gal] of gasoline, which led to a fire.
April 7, 2006	Walla Walla, Washington	A tractor-trailer was hit head on leading to a fire, which released 833 L [220 gal] of phosphoric acid.
March 30, 2006	London, Kentucky	A tanker truck struck another vehicle when it turned in front of the truck, which led to the release of 26,498 L [7,000 gal] of diesel fuel.
November 6, 2005	Stratford, Texas	A rear-end crash caused a tractor-trailer to burn to the ground releasing 799 L [211 gal] of isopropyl alcohol and 799 L [211 gal] of acetic acid.
October 3, 2005	Marathon, Florida	A tanker truck was struck head-on by a vehicle going the wrong direction, releasing 32,176 L [8,500 gal] of gasoline, which led to a fire.
August 16, 2005	Louisville, Kentucky	An accident between two passenger cars led to one passenger vehicle being sent into opposite traffic where it struck a tractor-trailer. The fuel tanks of the trailer exploded, which ignited the 313 kg [690 lbs] of dichloroisocyanuric acid.
May 28, 2005	Irving, Texas	A tanker truck involved in an accident fell off a bridge and resulted in a fire involving 18,927 L [5,000 gal] of gasoline.

Table A: Roadway Accidents With Insufficient Information To Determine Severity (continued)		
Date	**Location**	**Summary**
May 25, 2005	Bloomington, Minnesota	A tractor-trailer was exiting a construction zone, and the driver got confused, leading to the accident, which overturned the vehicle releasing 2,873 L [759 gal] of herbicide.
November 17, 2004	Briarcliff Manor, New York	A tanker truck collided with another vehicle leading to the release of 29,147 L [7,700 gal] of gasoline and a fire.
July 17, 2004	Why, Arizona	A tanker truck swerved to avoid an oncoming vehicle causing the tanker to overturn and releasing 33,690 L [8,900 gal] of gasoline, which led to a fire.
July 3, 2004	Amity, Oregon	A tanker truck was in an accident where another vehicle pulled in front of the tanker leading to the release of 23,470 L [6,200 gal] of gasoline.
December 10, 2003	Montverde, Florida	A vehicle crossed over the center lanes hitting a Federal Express vehicle releasing 13 kg [29 lbs] of detonating fuses, which led to a fire.
September 27, 2003	Newtown, Connecticut	A tanker truck was hit head on as a vehicle crossed over the center lane, which released 31,040 L [8,200 gal] of gasoline and led to a fire.
September 16, 2003	Detroit, Michigan	A tanker truck was cut off leading to loss of control of the tanker and subsequent fire consuming 50,725 L [13,400 gal] of gasoline.
July 19, 2003	Breckenridge, Texas	A tanker truck and tractor-trailer hit head on, leading to the release of 25,438 L [6,720 gal] of crude oil and a fire.
April 5, 2003	Yeehaw Junction, Florida	A tractor-trailer hit a parked vehicle on the roadside, leading to the release of various combustible liquids totaling roughly 1,022 L [270 gal] and a fire.
September 14, 2002	MacClenny, Florida	A tanker truck was hit by a vehicle that crossed the median, leading to the gasoline fire.
May 23, 2002	Forrest Park, Georgia	A highway accident involving multiple vehicles led to the puncture of the tractor fuel tanks, which released 16,080 L [4,248 gal] of paint and started a fire.
May 18, 2002	Moca, Puerto Rico	An accident at a gas station led to the puncture of a tanker truck cargo tank, which released 37,854 L [10,000 gal] of gasoline and started a fire.
April 15, 2002	Highland, Indiana	An intersection accident led to the release of 946 L [250 gal] of gasoline and started a fire.

Table A. Roadway Accidents With Insufficient Information To Determine Severity (continued)		
Date	Location	Summary
January 5, 2002	Birmingham, Alabama	A tanker truck hit a bridge when a vehicle pulled in front of the truck, releasing 37,476 L [9,900 gal] of gasoline and started a fire.
February 23, 2001	Mendenhal, Mississippi	A tractor truck struck a vehicle stopped in the right-hand lane, which led to the release of 757 L [200 gal] of gasoline and started a fire.
January 29, 2001	Barnesville, Minnesota	A tanker truck was hit by another tractor-trailer that did not stop at an intersection, releasing 33,323 L [8,803 gal] of gasoline and started a fire.
January 27, 2001	Roswell, Georgia	A tractor-trailer was hit by another vehicle changing lanes leading to the overturn of the trailer, released 757 L [200 gal] of diesel fuel, and started a fire.
September 25, 2000	East Islip, New York	A tanker truck was hit exiting a business leading to the release of 18,359 L [4,850 gal] of gasoline and starting a fire.
September 24, 2000	Meriden, Connecticut	A tanker truck was hit by another vehicle that crossed the center of the median, leading to the release of 32,577 L [8,606 gal] of gasoline, and started a fire.
September 14, 2000	Bainbridge, Indiana	A tanker truck was involved in an intersection accident that released 15,142 L [4,000 gal] of alcohol and started a fire.
August 12, 2000	Jacksonville, Florida	A tanker truck avoiding a spun-out vehicle lost control and overturned, leading to the release of 32,933 L [8,700 gal] of gasoline and starting a fire.
August 7, 2000	Macon, Georgia	A tanker truck attempted to avoid a collision leading to the release of 3,785 L [1,000 gal] of gasoline and starting a fire.
August 2, 2000	Las Vegas, Nevada	A tanker truck was hit by another tractor truck, which led to the release of 32,115 L [8,484 gal] of gasoline and started a fire.
June 16, 2000	Selah, Washington	A tanker truck was rear-ended, rupturing the tank, releasing 3,785 L [1,000 gal] of aviation fuel, and starting a fire.
May 1, 2000	El Reno, Oklahoma	A traffic accident released 757 L [200 gal] of gasoline and led to a fire.
April 21, 2000	Albany, Georgia	A passenger vehicle veered in front of a tanker truck, which tried to avoid the car. An oncoming tractor-trailer hit the tanker carrying 31,419 L [8,300 gal] of gasoline.
October 8, 1999	Indianapolis, Indiana	A tanker truck was hit broadside by another vehicle going through a red light. The tanker rolled, and its compartments ruptured, leading to the fire.
September 6, 1999	La Veta, Colorado	A multicar accident led to a fire and release of various hazardous materials.

Table A. Roadway Accidents With Insufficient Information To Determine Severity (continued)		
Date	**Location**	**Summary**
March 12, 1999	Buena Park, California	An accident with a tanker truck released 15,142 L [4,000 gal] of diesel fuel and 11,356 L [3,000 gal] of gasoline and led to a fire.
February 16, 1999	Columbus, Ohio	An accident between a tractor-trailer and another vehicle resulted in a fire and release of gasoline.
December 19, 1998	Westlake Village, California	An accident between a tanker truck and another vehicle released 33,312 L [8,800 gal] of gasoline and led to a fire.
May 23, 19998	Chester, Pennsylvania	A tanker truck attempted to avoid a vehicle that cut it off, leading to the overturn of the tanker, and releasing 33,690 L [8,900 gal] of gasoline, and leading to a fire.
January 15, 1998	Louis, Texas	An accident between two tractor-trailers led to the fire and release of anhydrous chromium trioxide.
October 31, 1997	Coraopolis, Pennsylvania	A vehicle ran into the trailer of an empty tanker truck leading to the fire and release of gasoline.
June 25, 1997	Philadelphia, Pennsylvania	A tractor-trailer attempting to avoid a vehicle that had cut it off led to the vehicle overturning and to a fire that released hydrated calcium hypochlorite.

APPENDIX B

This appendix lists all of the roadway accidents involving a fire and a collision that had sufficient information to determine whether they were a severe fire.

Table B: Roadway Accidents With Sufficient Information To Determine Severity			
Date	Location	Date	Location
October 5, 2008	Chattanooga, Tennessee	March 14, 2007	Picacho, Arizona
July 18, 2008	Prairie City, Iowa	February 19, 2007	Falkville, Alabama
July 5, 2008	Kingman, Arizona	December 15, 2006	Pittsburg, Kansas
June 30, 2008	Princeton, Minnesota	October 18, 2006	Macon, Georgia
April 26, 2008	High Springs, Florida	August 12, 2006	Lawton, Oklahoma
March 28, 2008	Chicopee, Massachusetts	April 21, 2006	Dahlonega, Georgia
March 24, 2008	Lower Makefield, Pennsylvania	April 15, 2006	Purchase, New York
November 7, 2007	Tallulah, Louisiana	January 20, 2006	Lagrange, Texas
June 23, 2007	Harrisburg, Pennsylvania	July 28, 2005	Kingsport, Tennessee
May 10, 2007	Howell Township, New Jersey	July 12, 2005	Ridgefield, Connecticut
March 26, 2007	Glendora, Mississippi	June 29, 2005	Kern, Colorado
May 11, 2005	Berks, Pennsylvania	April 2, 2001	Green Bay, Wisconsin
April 5, 2005	London, Kentucky	February 26, 2001	Springfield, Massachusetts
December 23, 2004	San Antonio, Texas	December 28, 2000	Fort Lauderdale, Florida
November 3, 2004	Snow Hill, Maryland	November 4, 2000	Centerville, Utah
September 13, 2004	Carlos, Texas	October 26, 2000	Aguilares, Texas
August 13, 2004	Berrien, Michigan	October 25, 2000	Mill Creek, Ohio
August 6, 2004	Maybell, Colorado	September 12, 2000	Sandersville, Georgia
August 3, 2004	Defiance, Ohio	August 2, 2000	Altoona, Pennsylvania
June 25, 2004	Chalmette, Louisiana	June 8, 2000	Alvwood, Minnesota
May 14, 2004	Cranbury, New Jersey	June 6, 2000	Carnesville Georgia
April 17, 2004	Greenville, North Carolina	March 15, 2000	Ellsworth, Wisconsin
March 25, 2004	Bridgeport, Connecticut	February 21, 2000	Henderson, Kentucky
March 20, 2004	Waco, Texas	February 17, 2000	Rolla, Missouri
March 13, 2004	Taylor, Michigan	November 22, 1999	Hammond, Indiana
January 13, 2004	Elk Ridge, Maryland	November 12, 1999	Hammond, Indiana
December 14, 2003	Greenville, Tennessee	October 23, 1999	Irving, Texas
October 19, 2003	Phoenix, Arizona	September 20, 1999	Pleasant View, Tennessee
October 1, 2003	Mission Viejo, California	August 11, 1999	Dawson Springs, Kentucky
September 23, 2003	Bell Gardens, California	August 3, 1999	Mitchell, South Dakota
July 24, 2003	Birmingham, Alabama	June 28,1999	Bruceville, Texas
May 18, 2003	Ovilla, Texas	January 25, 1999	Davie, Florida
November 29, 2002	Meeker, Colorado	December 18, 1998	Raleigh, North Carolina
September 16, 2002	Massey, Maryland	November 2, 1998	Government Camp, Oregon
August 1, 2002	Clear Lake, Iowa	October 17, 1998	Huntsville, Alabama
February 17, 2002	Santa Rosa, California	October 5, 1998	Woburn, Massachusetts
December 13, 2001	Gary, Indiana	July 7, 1998	Mustang, Oklahoma
December 4, 2001	Bakersfield, California	February 15, 1998	Wilmington, Delaware
November 29, 2001	Canton, Michigan	October 9, 1997	Yonkers, New York
November 23, 2001	Honea Path, South Carolina	September 5, 1997	Brownsburg, Indiana
October 23, 2001	Braselton, Georgia	August 11, 1997	Painter, Virginia
July 11, 2001	Detroit, Michigan	July 25, 1997	Bloomington, Illinois
June 9, 2001	Atlanta, Georgia	June 26, 1997	Columbus, Ohio
May 20, 2001	Carson, California	April 25, 1997	Jacksonville, Florida
May 18, 2001	Detroit, Michigan	February 21, 1997	Marshall, Illinois
May 1, 2001	Ramona, Oklahoma		

NRC FORM 335 (12-2010) NRCMD 3.7

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-7035

2. TITLE AND SUBTITLE

Analysis of Severe Roadway Accidents Involving Long Duration Fires

3. DATE REPORT PUBLISHED

MONTH	YEAR
02	2011

4. FIN OR GRANT NUMBER

J5639

5. AUTHOR(S)

G. Adams
T. Mintz

6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Center for Nuclear Waste Regulatory Analysis
6220 Culebra Road
San Antonio, TX 78228

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

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11. ABSTRACT *(200 words or less)*

The purpose of the study described in this report was to support the U.S. Nuclear Regulatory Commission in determining the different types and frequency of roadway accidents involving severe, long duration fires that could impact roadway transport of spent nuclear fuel (SNF). Roadway accident data were examined from the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration. From this study, the frequency of a severe fire occurring was estimated as roughly 4.90x10-5 accidents per million HAZMAT vehicle-km [7.89x10-5 accidents per million HAZMAT vehicle-mi]. This frequency represents 23 severe fire accidents occurring over the last 12 years (i.e., 1997 to 2008). None of the severe fire accidents involved the release of radioactive material. In general, severe fires are characterized by the release of flammable liquid (i.e., Class 3 HAZMAT), and in about 40 percent of the severe fires, more than 22,710 L [6,000 gal] of flammable liquid was released. Also, about half of the severe fires occurred on interstate highways with a median or divider and two of the severe fires occurred on interstate ramps. One of these accidents, occurring on a ramp, was likely in an enclosed area and as a result had the potential to generate a fire with higher average temperatures.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Transportation
Spent Nuclear Fuel
Roadway
Accident
Fire
Frequency

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page) unclassified

(This Report) unclassified

15. NUMBER OF PAGES

16. PRICE

NUREG/CR-7035

Analysis of Severe Roadway Accidents Involving Long Duration Fires

February 2011

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS