Rail Risk: Severe Fires and the Transportation of Spent Nuclear Fuel - 11582

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) ensures that packages designed to transport spent nuclear fuel (SNF) meet the regulations prescribed in 10 CFR Part 71. Historical rail accidents involving hazardous materials (HAZMAT) and long duration fires in the United States were studied using data from the Federal Railroad Administration and the Pipeline and Hazard Materials Safety Administration. The purpose of the study was to evaluate the types of accidents and accident parameters that could have an impact on SNF rail transport. This review determined that in the past 33 years of rail transport, there have been roughly 1,800 accidents that led to the release of HAZMAT. This study focused on accidents where HAZMAT was released from multiple train cars. From this study, the frequency of a severe fire occurring was estimated at 6.2×10^{-4} accidents per million freight train-km [1×10^{-3} accidents per million freight train-mi]. None of these accidents examined involved a reported release of radioactive material exceeding the limits set in 10 CFR Part 71.

Of the accidents reviewed, it was determined that only 9 rail accidents within the last 12 years involved a severe fire that could have provided a potential challenge to a SNF transportation package. This paper will provide a summary of this work and brief descriptions of the most severe accidents.

INTRODUCTION

NRC currently regulates the packaging for transportation of radioactive materials under 10 CFR Part 71. Under these regulations, a spent nuclear fuel (SNF) transportation package must be designed to withstand a series of hypothetical accident conditions, which include drop, crush, puncture, thermal (fire) exposure, and immersion in water of the package. This paper focuses on the thermal excursion evaluation. The current NRC regulations indicate that a SNF package must be designed to withstand a fully engulfing fire with an average flame temperature of at least 800°C (1,475°F) for a period of 30 minutes [1]. If subjected to a severe fire, the transportation package must maintain containment, shielding, and criticality functions throughout and after the thermal exposure.

In 2003, the National Academy of Sciences (NAS) formed the 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. The principal finding from the NAS committee was that there were no fundamental technical barriers to the safe transport of spent nuclear fuel or high-level radioactive waste [2]. In addition to this finding, the NAS committee indicated that the current international standards and U.S. regulations, at the time of writing of the committee's report, are adequate to ensure that the transportation package would provide adequate protection over various transportation conditions. However, the NAS committee noted that various technical reports indicated there were a very small number of severe accident conditions involving long duration fires that could potentially compromise the containment integrity of the 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 conditions. Based upon the NAS committee recommendation, NRC has continued to evaluate the parameters associated with accident events that involved long duration severe fires. This includes the data reported here, which describe the frequency and trends of rail accidents involving long duration fires.

Several studies have looked at the probability of transportation accidents involving SNF over the past few decades. Some of these previous studies are listed in Table I, which also compares the calculated railway accident rates between studies. Most of the data originate from the FRA database, which is a key source of railway transportation accident related data. A comparison of these previous reports, presented in Table I, shows that the earlier studies estimated a much higher accident rate (i.e., one to six accidents per hundred thousand train miles) compared to the later studies (i.e., two to three accidents per million train miles). This is likely a result of railway regulation changes that have improved the safety of train travel over the past 30 years.

The purpose of the work described in this paper was to assess rail transportation accidents involving long duration fires. The first objective was to analyze and tabulate statistics for railway accidents in the United States, including the frequency of railway accidents involving a long duration fire. The second objective was to analyze railway accidents and determine possible trends associated with these accidents.

Table I. Comparison of Train Accident Rates For Reports of Spent Nuclear Fuel Transportation

Source Document	Source of Data	Reported Accident Rate (Accidents/Million Train-Mile)
NRC, Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes [5]	Severities of Transportation Accidents, SLA–74–001 1975	65.1
NRC, Reexamination of Spent Fuel Shipment Risk Estimates [6] **and** Shipping Container Response to Severe Highway and Railway Accident Conditions [7]	FRA Rail Data 1975–1982	12.1
U.S. Department of Energy, Yucca Mountain EIS [8]	Association of American Railroads State Data 1994–1996	3.67
EPRI, Criticality Risks During Transportation of Spent Nuclear Fuel [9]	FRA Rail Data 2000–2006	2.67

RAIL ACCIDENT DATA

The data analysis in this paper focused on HAZMAT release accidents involving multiple cars to identify where a fire occurred. The focus of this report was on HAZMAT data because it is believed that the regulations used for HAZMAT transport will be similar to that for SNF transportation. The main sources of data used in this paper were based on the accident data developed by the FRA [3] and HAZMAT data developed by the U.S. Department of Transportation, PHMSA, and the Office of Hazardous Materials Safety [4]. Each year FRA collects data from more than 600 railroads, which it uses to (a) effectively carry out its regulatory and enforcement responsibilities under the federal railroad safety statutes, (b) determine comparative trends of railroad safety, and (c) develop hazard elimination and risk reduction programs that focus on preventing railroad injuries and accidents. Unfortunately, the FRA database does not always indicate whether the accident occurred along with a fire, and additional information provided by the PHMSA database was required to examine whether (a) HAZMAT was released and (b) a fire resulted from the release of HAZMAT.

ANALYSIS OF ACCIDENT DATA

Accident Frequency Calculations for All Railway Accidents

Different sources of railway accident data define the word “accident” differently. In this paper, the term “accident” is used to reflect where a single train derailed as well as where a train collided with an object (e.g., a backhoe left on the track by vandals) or another train.

The analysis results of the FRA data between 1975 and 2008 are shown in Table II. The rates in this table are the number of accidents divided by the total freight train miles. For example, the rate for total freight train accidents in 1975 was 10.35 accidents per million train miles. The data show the rate of accidents has decreased over the past 25 years, which is consistent with the information presented in Table I. The data review focused on multiple car accidents because these accidents will most likely lead to more severe fires due to the larger amount of hazardous materials involved when multiple rail cars are involved. These accidents, where HAZMAT was released from multiple cars, were cross-referenced to the PHMSA data to determine if a fire had occurred during the accident. Because the data for PHMSA were limited to dates between 1997 and 2008, only the accidents in this time period were cross-referenced. The results of this cross-reference are shown in Table III, and can be compared with the shaded data in Table II.

As shown in Table II, for accidents with release of HAZMAT, the total accident rate for the past 12 years (i.e., 0.06 accidents per million freight train miles) is approximately 60 percent of the total accident rate for the entire 34 years (i.e., 0.10 accidents per million freight train miles). The single car and multiple car HAZMAT release accidents are shown separately in the table. The rates for these accidents show similar decreases in the last 12 years when compared to their accident rates over the last 34 years.

Table II. Overall FRA Railway Accident Data

Year	Freight Train Miles	Freight Train Accidents		Freight Accidents with Release of HAZMAT					
				Total Accidents With Release HAZMAT		Single Car		Multiple Cars	
	(million)		Accident Rate		Accident Rate		Accident Rate		Accident Rate
1975	570	5,906	10.35	83	0.15	62	0.11	21	0.04
1976	585	7,187	12.28	113	0.19	88	0.15	25	0.04
1977	566	7,192	12.70	114	0.20	86	0.15	28	0.05
1978	568	7,512	13.23	138	0.24	102	0.18	36	0.06
1979	577	6,475	11.23	105	0.18	81	0.14	24	0.04
1980	542	5,339	9.85	119	0.22	94	0.17	25	0.05
1981	511	3,617	7.08	77	0.15	60	0.12	17	0.03
1982	433	2,903	6.70	59	0.14	39	0.09	20	0.05
1983	422	2,598	6.16	52	0.12	45	0.11	7	0.02
1984	448	2,642	5.90	54	0.12	40	0.09	14	0.03
1985	431	2,230	5.17	54	0.13	41	0.10	13	0.03
1986	428	1,894	4.42	51	0.12	39	0.09	12	0.03
1987	439	1,842	4.20	50	0.11	34	0.08	16	0.04
1988	460	1,936	4.21	44	0.10	29	0..06	15	0.03
1989	469	1,996	4.26	56	0.12	38	0.08	18	0.04
1990	460	1,941	4.22	35	0.08	19	0.04	16	0.03
1991	436	1,774	4.07	47	0.11	31	0.07	16	0.04
1992	448	1,539	3.43	27	0.06	22	0.05	5	0.01
1993	464	1,634	3.52	29	0.06	21	0.05	8	0.02
1994	495	1,578	3.19	36	0.07	30	0.06	6	0.01
1995	506	1,578	3.12	27	0.05	19	0.04	8	0.02
1996	507	1,559	3.08	34	0.07	24	0.05	10	0.02
1997	512	1,529	2.98	31	0.06	25	0.05	6	0.01
1998	520	1,612	3.10	42	0.08	28	0.05	14	0.03
1999	542	1,609	2.97	41	0.08	32	0.06	9	0.02
2000	549	1,763	3.21	35	0.06	23	0.04	12	0.02
2001	538	1,773	3.30	32	0.06	17	0.03	15	0.03
2002	547	1,562	2.86	31	0.06	22	0.04	9	0.02
2003	561	1,618	2.88	30	0.05	25	0.04	5	0.01
2004	584	1,810	3.10	31	0.05	21	0.04	10	0.02
2005	597	1,712	2.87	39	0.07	29	0.05	10	0.02
2006	624	1,622	2.60	30	0.05	19	0.03	11	0.02
2007	586	1,465	2.50	46	0.08	34	0.06	12	0.02
2008	565	1,290	2.28	22	0.04	16	0.03	6	0.01
12 Years	6725	19,365	2.88	410	0.06	291	0.04	119	0.02
All Years	17,489	92,237	5.27	1814	0.10	1335	0.08	479	0.03

Accidents for the last 12 years (shaded data) were analyzed to determine if a fire occurred, shown in Table III.

The rate for multiple car HAZMAT release accidents involving a fire is shown in Table III and is approximately 0.003 accidents per million freight train miles, which is about 15 percent of the accident rate for multiple car HAZMAT release accidents over the same 12 years as shown in Table II.

Table III. Accident Data for Accidents with Release of HAZMAT from Multiple Cars Involving a Fire

Year	Freight Train Miles (Million)	Total	Accident Rate
1997	512	0	0.000
1998	520	2	0.004
1999	542	0	0.000
2000	549	2	0.004
2001	538	2	0.004
2002	547	0	0.000
2003	561	2	0.004
2004	584	1	0.002
2005	597	2	0.003
2006	624	1	0.002
2007	586	5	0.009
2008	565	3	0.005
12 Years	6,725	20	0.003

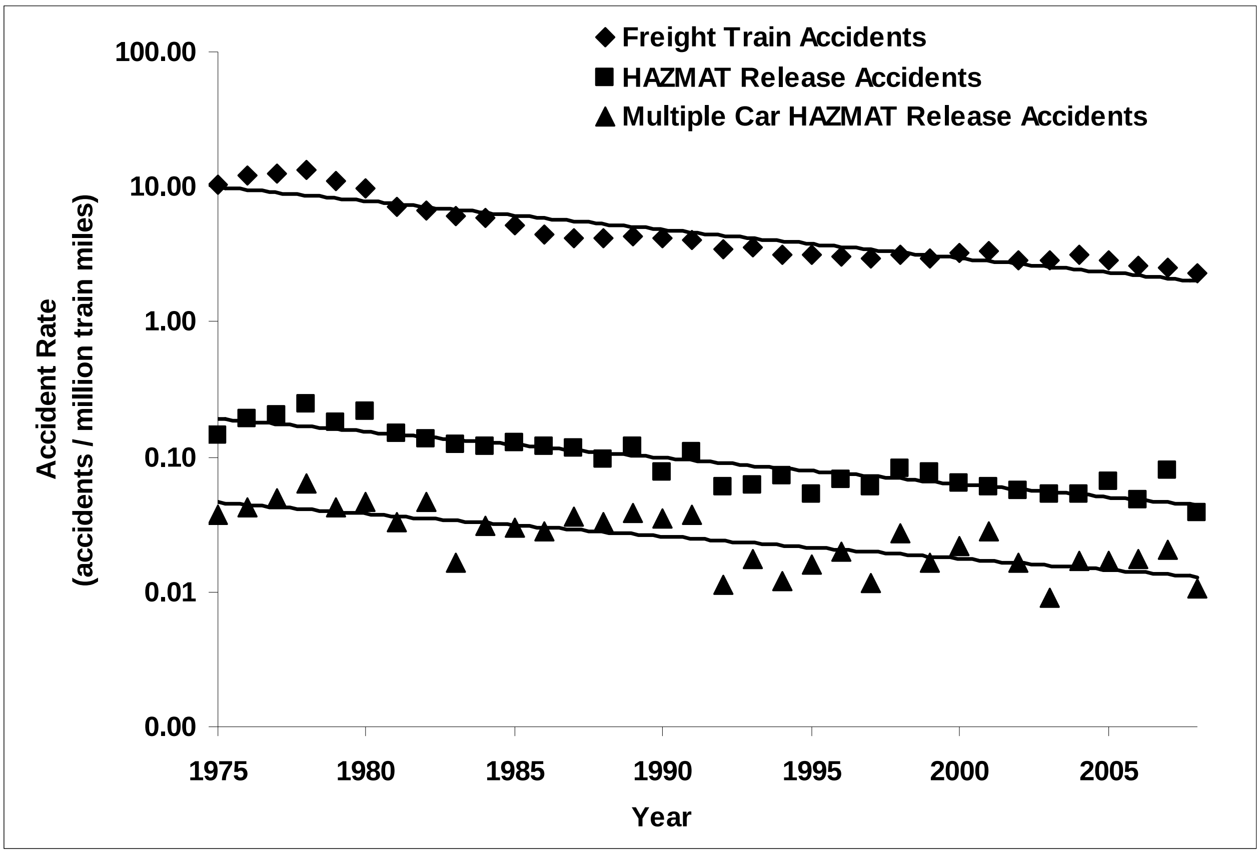

FIGURE 1. Summary of Railway Accidents From 1975 to 2008

Accident Trends for All Railway Accidents

To understand the key trends associated with railway accidents that may lead to HAZMAT releases and a fire, the parameters associated with the railway accidents were examined for the FRA data collected during the timeframe of 1997 to 2008. As shown in Figure 2, 89 multiple car HAZMAT release accidents occurred on the main line (i.e. a track that is used for through trains), while 30 multiple car HAZMAT release accidents occurred off the main line (i.e., branch tracks or sidings). Of the 89 accidents occurring on the main line, 17 resulted in a fire.

However, there were eight accidents that did not have enough detail to determine whether a fire had or had not occurred. Similarly, for the 30 accidents occurring off the main line, three resulted in a fire, while six did not have enough information to determine whether a fire had occurred.

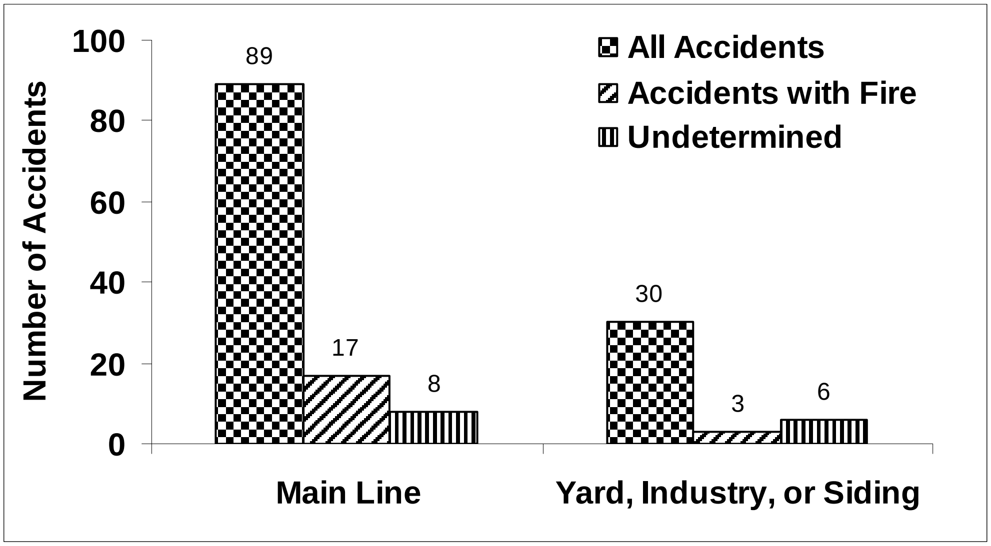

FIGURE 2. Multiple Car HAZMAT Release Accidents From 1997 to 2008

As shown in Figure 3, less than 25 percent (i.e., 21 out of 89) of the main line accidents occurred in the last three years (i.e., 2006 through 2008); however, almost half (i.e., eight out of 17) of the HAZMAT release accidents involving a fire occurred in the last three years. On average, for the 12 years from 1997 to 2008, between seven and eight multiple car HAZMAT release accidents occurred per year and the number of accidents for 2007 and 2008 fell just above or just below the average (i.e., nine for 2007 and five for 2008). Assuming all of the eight undetermined accidents resulted in a fire, then for the 12 years from 1997 to 2008, roughly, two multiple car HAZMAT release accidents resulted in a fire per year. For the years 2007 and 2008, the number of these fire accidents was more than twice the average (i.e., four for 2007 and three for 2008).

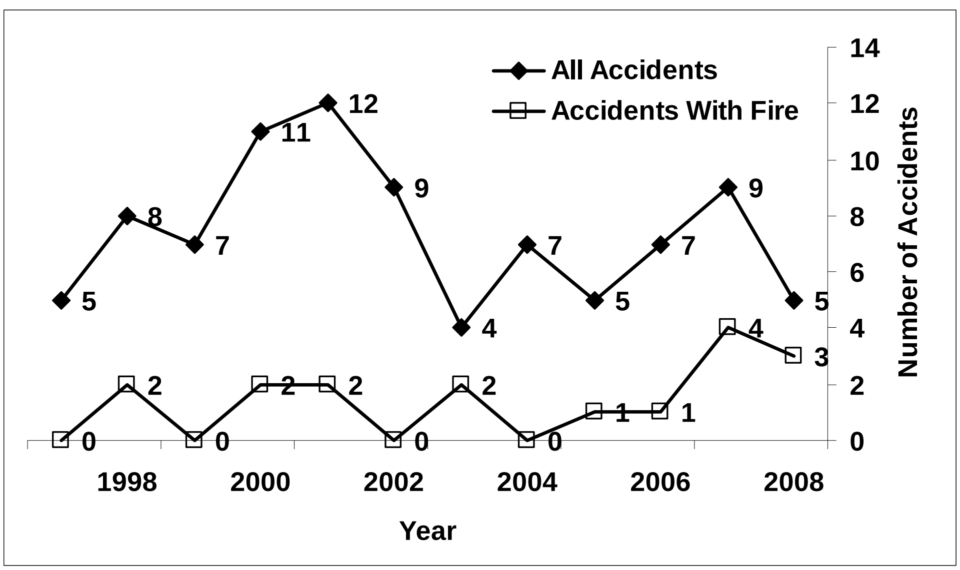

FIGURE 3. Number of Mainline Multiple Car HAZMAT Release Accidents and Multiple Car HAZMAT Release Accidents Resulting in a Fire by Year

The flammable material and oxidizers HAZMAT classes for the 89 accidents occurring on the main line are shown in Figure 4. This figure only shows the numbers associated with flammable material and oxidizers and does not include other classes of hazardous material that make up the overall 89 accidents. As shown in Figure 4, Class 3 HAZMAT (i.e., flammable liquid) was released in more than half of the 89 accidents (i.e., 46 out of 89) and in all but one of the accidents that resulted in a fire (i.e., 16 out of 17). In some accidents, such as the one occurring October 20, 2006, in New Brighton, Pennsylvania, multiple cars released flammable liquid (approximately 20 cars released an estimated 485,278 gallons of ethanol) [10]. The single fire accident in Figure 4, for which staff did not identify a Class 3 HAZMAT release, instead the release involved Class 4.1 HAZMAT (i.e., flammable solid) and occurred on December 18, 2000, in Plymouth, Minnesota [3]. In this accident, approximately 19,000 gallons of molten sulfur were released from six cars. As shown in Figure 4, Class 2.1 HAZMAT (i.e., flammable gas) was released in seven accidents, and a fire resulted in six out of the seven accidents from 1997 to 2008 on the main line. In all six of these accidents, flammable gas was released with flammable liquid. Figure 4 also shows seven accidents in which Class 5.1 HAZMAT (i.e., oxidizer) was released from 1997 to 2008 on the main line. The 1 accident that resulted in a fire occurred in conjunction with a release of approximately 57,171 gallons of flammable liquid. The majority (i.e., 85 out of 89) of multiple car HAZMAT release accidents that occurred on the main line involved a derailment. However, four accidents involved an impact or collision. Three of the four impacts or collision accidents resulted in a fire, while 14 of the 85 derailment accidents resulted in a fire.

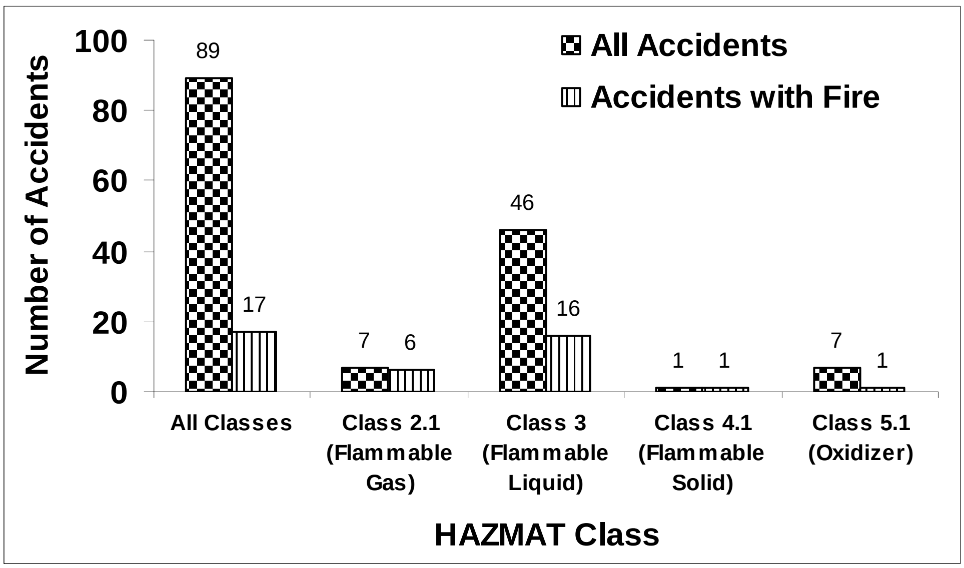

FIGURE 4. Number of HAZMAT Release Accidents From 1997 to 2008 That Occurred on the Main Line Showing Four of the HAZMAT Classes Involved. In Some Accidents, the Release Involved Material from More Than One HAZMAT Class.

The maximum allowed freight train speed in the United States increases with increasing track class, as shown in Table IV [3].

TABLE IV. Maximum Speed for Freight Trains by Track Class [3]

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

Figure 5 shows the number of multiple car HAZMAT release accidents increased from Class 1 to Class 4 track but then decreased for Class 5 track. Figure 5 also shows the multiple car HAZMAT release accidents that occurred on the main line separated by track class. As shown in this figure, of the 89 accidents occurring on the main line, approximately 43 percent of them (i.e., 38 out of 89) occurred on Class 4 track. Assuming none of the eight undetermined accidents resulted in a fire, then almost half of the accidents (i.e., eight out of 17) involving a fire occurred on Class 4 track. The remaining accidents involving a fire were divided evenly among Classes 2, 3, and 5 track. Three accidents occurred on each of these three classes of track.

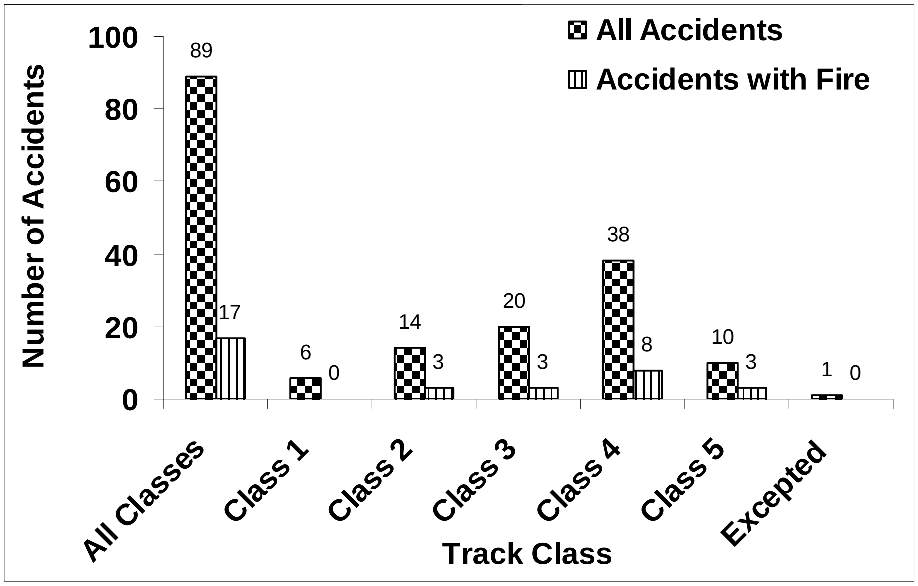

FIGURE 5. Number of Multiple Car HAZMAT Release Accidents From 1997 To 2008 That Occurred on the Main Line Separated by Track Class

Figure 6 shows the number of multiple car HAZMAT release accidents that occurred from 1997 to 2008 on the main line separated by train speed. In this figure, speed was arbitrarily separated into 20-mph groups with the highest speed for the last group corresponding to the maximum freight train speed for Class 5 track. As shown in Figure 6, for the 89 accidents occurring on the main line, approximately 40 percent of them (i.e., 36 out of 89) occurred between 21 and 40 mph, with approximately 31 percent of them (i.e., 28 out of 89) occurring at higher speeds between 41 and 60 mph. For accidents involving a fire, however, a greater percentage of the accidents occurred in the higher speed range (i.e., 41 to 60 mph). Almost half of them (i.e., eight out of 17) occurred from 41 to 60 mph, whereas only 35 percent of them (i.e., six out of 17) occurred in the lower speed range of 21 to 40 mph.

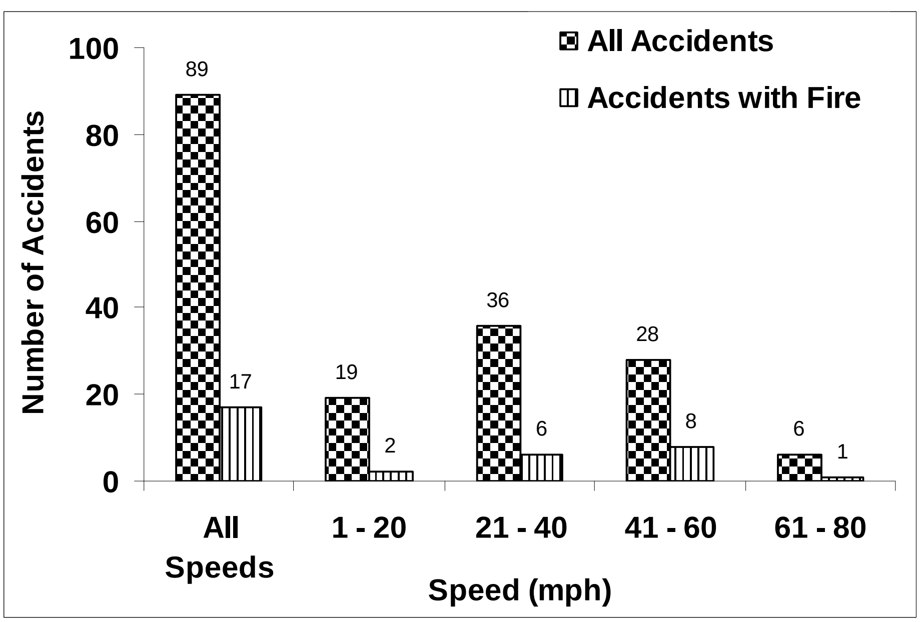

FIGURE 6. Number of Multiple Car HAZMAT Release Accidents From 1997 To 2008 That Occurred on the Main Line Separated by Speed

Frequency Calculations for Accidents Involving Severe, Long Duration Fires

To evaluate the frequency of severe fire accidents that have occurred in the past 12 years, a severe fire accident must be defined. In lieu of quantitative identification of a severe fire, the analysis described in this paper attempted to define a severe fire using two criteria. The first criterion was that a railcar must have been substantially engulfed in a fire that persists for an extended period of time. The second criterion was that the principal source of fuel for the substantially engulfing fire must have been derived from another railcar. The purpose of this second criterion was to restrict the term "severe fire" to those fires that could have affected SNF packages (implicitly assuming that the packages and their transporting railcars do not provide fuel to a fire) and exclude railcar fires that were self-fueled. Thus, severe fires are not just large fires, but fires that have the capacity to potentially affect SNF packages.

As a consequence, using rail accident reports as a basis to classify rail fires often required the use of inferences rather than strict descriptions, and these inferences may have been interpreted subjectively. However, as a general guideline for this analysis:

- "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.

- "Substantially engulfed" was interpreted as a fire that optically engulfs (or could have optically engulfed) at least 30 percent of the surface area of a non-fuel source bearing railcar, or damage from the fire appeared to have affected at least 30 percent of the surface area of a non-fuel source bearing railcar.

- "Principal source of fuel" was interpreted as meaning that, at some point in time, the fire was fueled by materials from another railcar. This point arose from an occasional ambiguity in determining whether a railcar spawned a secondary fire as a result of a fire or was the initial source of a fire.

As described in the previous section, on average for the total number of railway accidents, only a few were identified as having potentially severe fires. The process of identifying those accidents with severe fires began by identifying and focusing attention on accidents that involved the release of HAZMAT from multiple railcars and thus, were potentially capable of supporting a severe fire. As described, this reduced the number of candidate accidents to just 119 accidents (i.e., 89 accidents on the main line and 30 accidents off the main line) that potentially had a sufficient amount of fuel to support a severe fire. Of the 89 accidents on the main line, just 17 involved a fire. Of the 30 accidents off the main line, just three involved a fire.

The 20 rail accidents involving a fire were initially identified through a search of the FRA database. After identifying these accidents, details about these accidents were then derived from available National Transportation Safety Board (NTSB) reports or briefs. However, of the 20 accidents initially identified, reports were not found for several accidents. These missing reports were either pending (for recent accidents) or simply not available through the NTSB electronic publications for railroad accidents. Consequently, these events could not be evaluated to determine fire severity, nor were they included in the frequency calculation and trend analysis of severe accidents. Of the 20 initially identified accidents, accident reports were found for 12. Out of these 12 accidents, nine (i.e., eight on the main line and one off the main line) were classified as a severe accident based on the criteria previously discussed. The severe accidents were further classified as either widespread severe fire accidents (i.e., 10 or more railcars were affected by the severe fire) or local severe fires accidents (i.e., fewer than 10 railcars were affected by the severe fire). The calculated frequency for the 12-year period, shown in Table V, is roughly 0.001 severe fire accidents per million freight train miles of railway travel or about one severe accident per every one billion train miles. This is approximately 0.035 percent of the total accident rate (i.e., 3.85 accidents per million freight train miles).

TABLE V. Severe Fire Railway Accident Data

Year	Freight Train Miles (Million)	Severe Fire Events		Rate
		Widespread	Local	

1997	512	0	0	0
1998	520	0	0	0
1999	542	0	0	0
2000	549	1	0	0.002
2001	538	0	1	0.002
2002	547	0	0	0
2003	561	0	1	0.002
2004	584	0	1	0.002
2005	597	0	1	0.002
2006	624	1	0	0.002
2007	586	0	3	0.005
2008	565	0	0	0
Total	6725	9		0.001

Trends for Accidents Involving a Severe Fire

As indicated previously, only two of the 20 accidents were designated as a widespread railcar severe fire. The first accident was on October 20, 2006, in New Brighton, Pennsylvania, and the second was on May 27, 2000, in Eunice, Louisiana. Both derailments involved track failure in the vicinity of a bridge. For the accident in Eunice, Louisiana, the rails were misaligned due to broken joint bars [12]. For the accident in New Brighton, Pennsylvania, the rail fractured under the load of the train from an undetected defect [10]. Both trains had several HAZMAT cars, and many of these cars released HAZMAT. These accidents are characterized by trains that had a large fraction of its cars transporting HAZMAT and in which a significant number of cars were damaged in the derailment and ensuing fire. Many of the damaged cars released HAZMAT, and a significant amount of that material was flammable liquid. Other parameters associated with these accidents do not appear to be significantly different when compared to other accidents involving a fire. The accidents occurred on Classes 3 or 4 track where nearly 65 percent of the accidents involved a fire (i.e., 11 out of 17). In addition, these two accidents occurred at speeds less than 40 mph where almost half of the accidents (i.e., eight of the 17) involving a fire occurred.

There were only six severe fire accidents where a minimal number of cars were exposed to fire [12-17]. Five of the six accidents involved a derailment, and the remaining one was a head-on collision. There were some similarities in the accidents. Four of the accidents occurred at speeds above 40 mph, where more than half of the accidents (i.e., nine out of 17) involving a fire occurred. These same accidents involved a HAZMAT release from five to seven cars. These same four accidents involved the release of Class 3 HAZMAT (i.e., flammable liquid). Three out of the four accidents also involved the release of Class 2.1 HAZMAT (i.e., flammable gas). All four accidents resulted in the release of thousands of gallons of flammable liquid or flammable gas. The fifth accident, which occurred at a lower speed, was on Class 2 track, and involved a release from a fewer number of cars. This fifth accident was different because it occurred in a tunnel, which may have created a constrained environment and contributed to causing a severe fire.

Because of the limited amount of data (i.e., nine accidents over a 12-year period), it is difficult to determine trends for railway accidents involving a severe fire. However, the severe fire accidents (both widespread and local) are generally characterized by derailments in which flammable liquid or gas was released from several cars (i.e., five or more cars). In general, these accidents were caused by rail failure. They generally occurred at speeds from just below 40 mph to just below 50 mph.

CONCLUSION

Based on the NAS recommendations, NRC is identifying the types of accident parameters that could impact the rail transport of SNF. The objective of the work described in this paper was to review available railway accident statistics and assess possible trends associated with railway severe fire accidents. The results of this analysis suggest that in the previous 12 years, the rail accident rate is roughly 2.88 accidents per million freight train miles. This falls within the range of the previous studies by EPRI and the U.S. Department of Energy, which calculated rates between two and four accidents per million train miles.

The work described in this paper further examined the frequency of accidents involving a fire and release of hazardous material. The paper focused on accidents where multiple car releases of HAZMAT that could serve as a source of fuel occurred, because these types of accidents would more likely result in a SNF transportation package being exposed to a fire. The results indicated that the frequency for multiple car release of HAZMAT resulting in a fire is 0.003 accidents per million train miles or one accident per 300 million train miles. These fire-related accidents were further separated into two categories: (a) those considered to be a severe fire, which was based on the fire being able to partially engulf a railcar for an extended period of time, and (b) those where the source of fuel for the engulfing fire was derived from another railcar. With these criteria in place, the frequency for a severe accident was calculated at 0.001 accidents per million train miles or about one accident per 1 billion train miles.

To understand some of the factors that may lead to a railway accident involving a severe fire, the accident trends were evaluated for severe fires. Although there is limited data (i.e., due to only nine accidents during the last 12 years that were judged to be in the severe fire category), some trends of the data were determined. The railway severe fire accidents were generally characterized by derailments where a flammable liquid or gas was released from several cars (i.e., five or more). The speeds for these accidents were typically from about 40 mph to about 50 mph.

Based on the analysis of the accident data, a very small frequency would cause severe fire accidents that could affect a SNF transportation package. Limiting the transport of SNF packages to trains without any flammable liquid or gas (i.e., dedicated trains) would likely reduce the frequency even more.

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