

Just How Risky Is It? Comparisons of the Risks of Transporting Radioactive Waste- 10535

Earl. P. Easton, Christopher S. Bajwa
U.S. Nuclear Regulatory Commission
Washington, DC 20555

ABSTRACT

The US Nuclear Regulatory Commission (NRC) completed an analysis of historical rail accidents (from 1975 to 2005) involving hazardous materials and long duration fires in the United States. The analysis was initiated to determine what types of accidents had occurred and what impact those types of accidents could have on the rail transport of spent nuclear fuel. The NRC found that almost 21 billion miles of freight rail shipments over a 30 year period has resulted in a small number of accidents involving the release of hazardous materials, eight of which involved long duration fires. All eight of the accidents analyzed resulted in fires that were less severe than the “fully engulfing fire” described in the NRC regulations for radioactive material transport found in Title 10 of the Code of Federal Regulations, Part 71, Section 73, as hypothetical accident conditions. None of the eight accidents involved a release of radioactive material. This paper describes the eight accidents in detail and examines the potential effects on spent nuclear fuel transportation casks exposed to the fires that resulted from these accidents.

NOMENCLATURE

AAR- Association of American Railroads
CFR- Code of Federal Regulations
CRUD- Chalk River Unknown Deposit¹
DOE- United States Department of Energy
FRA- Federal Railroad Administration
HLW- High Level Radioactive Waste
ISO- International Organization for Standardization
LPG- Liquefied Petroleum Gas
NTIS- National Technical Information Service
NTSB- National Transportation Safety Board
NRC- United States Nuclear Regulatory Commission
SNF- Spent Nuclear Fuel

BACKGROUND

As part of its investigation of the impact of the Baltimore tunnel fire of 2001 [1] (herein referred to as the Howard Street tunnel fire) on the transportation of spent nuclear fuel, NRC staff conducted a detailed review of documentation related to rail transportation accidents in the United States. The staff reviewed accident reports (particularly those of the NTSB), historical media accounts, and data from the Federal Railroad Administration (FRA) safety database and from the Association of American Railroads (AAR). This review showed that severe rail fires, either in tunnels or open environments, are extremely infrequent events (on the order of approximately 1 such event for every 3 billion miles of rail transport).

RAIL ACCIDENT DATA

The staff’s review revealed several facts about rail accidents in the United States in general, and those involving hazardous materials specifically. These facts, which are summarized below, aid in putting severe rail transportation accidents into perspective.

- In nearly 21 billion miles of freight rail travel on American railroads between 1975 and 2005, there have been 1700 reported incidents (accidents) involving the release of hazardous materials.
- Many of the 1700 incidents involved minor releases of non-flammable hazardous materials. None of the 1700 incidents involved the release of radioactive material.

¹ Generic term for various residues deposited on fuel rod surfaces, originally coined by Atomic Energy of Canada, Ltd. (AECL) to describe deposits observed on fuel removed from the test reactor at Chalk River.

- Of the 1700 incidents, there were 8 that involved a significant quantity of flammable material and resulted in a long duration fire. These incidents² were as follows:
 - 1) Derailment of CSXT freight train, Baltimore, Maryland, July 18, 2001 [NTSB Brief RAB-04-08]
 - 2) Derailment of Union Pacific Freight train, Eunice, Louisiana, May 27, 2000 [NTSB report RAR-02-03; NTIS report PB2002-916303]
 - 3) Derailment of Wisconsin Central freight train, Weyauwega, Wisconsin March 4, 1996³
 - 4) Derailment of BNSF freight train, Cajon Pass, California, February 1, 1996 [NTSB report RAR-96-05; NTIS report PB96-916305]
 - 5) Derailment of CSXT freight train, Akron, Ohio, February 26, 1989 [NTSB report HZM-90-02; NTIS report PB90-917006]
 - 6) Derailment of MT Rail freight train, Helena, Montana, February 2, 1989 [NTSB report RAR-89-05; NTIS report PB89-916305]
 - 7) Derailment of CSXT freight train, Miamisburg, OH, July 8, 1986 [NTSB report HZM-87-01; NTIS report PB-87-917004]
 - 8) Derailment of Illinois Gulf Central freight train, Livingston, Louisiana, September 28, 1982 [NTSB report RAR-83-05; NTIS report PB83-916305]

ANALYSIS OF ACCIDENT DATA

Of these eight accidents, only one (the Howard Street tunnel fire) occurred in a tunnel. Based on an examination of the NTSB accident reports on the seven accidents listed above that did not occur in a tunnel, the staff concluded that none of them could have provided a fully engulfing fire environment for a spent fuel package, had one been involved in the event.

This conclusion is based on three mitigating factors present in the accidents examined above: (1) the potential proximity of a hypothetical SNF transportation package to the fire that occurred, (2) the available fuel for the fire, and (3) the emergency response time for each accident. These factors are expanded upon below:

(1) Proximity:

- Using diagrams of the rail car configurations in the seven accidents, as given in the NTSB reports, a rail car carrying a spent fuel package, could not have been located adjacent to any tank cars that ruptured in these accidents. This is the case largely because a spent fuel cask must be separated from other rail cars carrying hazardous materials by a buffer car.[2]
- An SNF package, had one been involved, would not have been positioned near enough to the burning flammable material in these accidents to be fully engulfed. This point is further discussed in the context of the Weyauwega derailment and fire later in the paper.

(2) Fuel for the fire:

- The flammable material involved in a majority of the accidents were gasses that resulted in localized pressure fires, so these accidents did not involve the pooling of flammable liquids.
- In those that did involve flammable liquids, pooling did not occur due to the nature of the track bed, which is often elevated over porous media, thus allowing for liquids to drain away from the derailment site rather than pool.

(3) Response time:

- The emergency response times ranged from approximately a few minutes up to two hours for the accidents reviewed. Longer response times were often associated with derailments in remote locations, where the potential consequences of a release of radioactive material to the health and safety of the public, would be mitigated.

² The reports on these incidents are available on the NTSB web site, www.nts.gov, under the link "Accident Reports", or from the National Technical Information Service (NTIS) web site, www.ntis.gov.

³ The NTSB did not issue a report on this accident. Information describing the accident is available in the public docket, *National Transportation Safety Board Public Docket for Railroad Accident at Weyauwega, WI, March 4, 1996*. Docket ID: 8867, Released August 18, 1997, Washington, D.C. This document is available at: <http://www.postcrescent.com/specials/assets/APCweyauweatrain/default.htm>

- Response efforts often included cooling tank cars with water, in order to prevent explosions, which also had the effect of minimizing fire intensity and duration.
- While this response time (in general) exceeds the hypothetical accident condition (HAC) fire duration of 30 minutes, as specified in 10 CFR Part 71 §73 [3] for radioactive material packages, the actual fires examined were not fully engulfing as specified in the HAC fire condition.

DISCUSSION OF RAIL ACCIDENTS

A brief description of 6 of the 8 accidents listed above is provided below. An in-depth review of one of the worst accidents, the derailment of a Wisconsin Central freight train in Weyauwega, Wisconsin, is provided in the next section along with an assessment of the potential impact of this accident on the performance of a spent fuel transportation package.

The Howard Street tunnel fire will then be discussed in the following section, as this accident is the only severe rail tunnel fire involving hazardous materials shipments that has occurred in the nearly 21 billion rail miles of transportation that took place in the United States between 1975 and 2005 and is unique in that none of the mitigating factors noted above (for non-tunnel fires) were acting to significantly limit the severity or duration of the fire. This accident has been the subject of a major study by the NRC [1] including an analysis of the effects of this tunnel fire on three different spent fuel transportation packages. The results of the NRC's study will be summarized.

Derailment of Union Pacific Freight Train, Eunice, Louisiana

In May of 2000, a 113 car Union Pacific Railroad train derailed near Eunice, Louisiana. Of the derailed cars, 15 contained hazardous materials and 2 contained hazardous materials residue. The derailment resulted in a release of hazardous materials with explosions and fire. About 3,500 people were evacuated from the area, and no injuries were reported. The explosions occurred almost 1 hour and 45 minutes after the fire started, and most likely involved two tank cars filled with methyl chloride (a flammable gas).

Derailment of BNSF freight train, Cajon Pass, California

In February of 1996, a runaway Atchison, Topeka and Santa Fe Railway Company (ATSF) freight train (H-BALT1-31), was traveling westbound on the ATSF south main track when it derailed near Cajon Junction, California. The derailment involved five cars containing hazardous materials, and the ensuing fire engulfed the train and the surrounding area. Emergency response personnel arrived at the scene within 10 minutes, however, due to the uncertainty of the locations of the train crew, firefighting efforts did not commence until the evening of the accident. Local roads were closed due to the toxic emissions from the tank cars. Over the next four days firefighters removed the tank cars and extinguished the fires as needed. One tank car had to be ventilated by using plastic explosives due to the concern over a possible overpressure explosion.

Derailment of CSXT freight train, Akron, Ohio

In February of 1989, a CSXT freight train derailed 21 cars, nine of which contained butane, adjacent to a B.F. Goodrich Chemical Company plant in Akron, Ohio. Evacuations of the surrounding areas were conducted and the localized fires burned up to 5 days after the derailment. None of the tank cars had ruptured due to the fire.

Derailment of MT Rail freight train, Helena, Montana

In February of 1989, freight cars from a Montana Rail Link (MRL) train rolled down a mountain grade and struck a stationary helper locomotive in Helena, Montana. The collision resulted in a derailment and fire, followed by explosions, involving tank cars carrying hydrogen peroxide, isopropyl alcohol, and acetone. Evacuations were conducted of the surrounding area and firefighting activities were initiated and sustained until the fire was extinguished the next day.

Derailment of CSXT freight train, Miamisburg, Ohio

In July of 1986, 15 cars of a Baltimore and Ohio Railroad Company freight train derailed near Miamisburg, Ohio. Three of the 15 derailed cars contained yellow phosphorus, molten sulfur, and tallow. An evacuation of the area was conducted as a precaution. Firefighters brought the fire under control about four hours after the derailment occurred. During removal of the tank cars, the concrete structure supporting the phosphorus tank car collapsed, and the molten phosphorus re-ignited. A second evacuation was initiated and firefighters re-engaged the fire, attempting to allow for a controlled burning of the phosphorus in the tank car. After the contents of the car were sufficiently consumed, the car was removed for dismantling and the remaining phosphorus was loaded into drums for disposal. The process of burning down the inventory of the tank car took approximately 3 days.

Derailment of Illinois Gulf Central freight train, Livingston, Louisiana

In September of 1982, an Illinois Central Gulf railroad freight train derailed 43 cars on a single main track in Livingston, Louisiana. A total of 20 cars were punctured or breached in the derailment. Tank cars carrying vinyl chloride were breached and ignited, causing a severe fire that engulfed a nearby residence. An evacuation of nearby residents was conducted. Thermally induced explosions of two tank cars that had not been punctured also occurred. Over the next two weeks firefighters attempted to control the burning in several of the tank cars while the hazardous contents were vented or removed. Several tank cars exploded during this time. All fires were finally extinguished 15 days after the derailment.

DERAILMENT OF WISCONSIN CENTRAL FREIGHT TRAIN, WEYAUWEGA, WISCONSIN

In March of 1996, 37 cars of a Wisconsin Central Railroad train derailed at a road crossing in Weyauwega, Wisconsin. Figure 1 shows a photograph taken at the time of the accident.



Fig. 1. Photograph of derailment and fire at Weyauwega, Wisconsin

Among the 37 derailed cars were 7 tank cars of liquefied petroleum gas (LPG), 7 tank cars of liquefied propane gas, and 2 tank cars of sodium hydroxide (a non-flammable corrosive). As a result of the derailment, three of the tank cars were breached and the propane and LPG immediately caught fire.

When firefighters arrived (within five minutes of the derailment) at least 3 severe fires were burning, which included buildings surrounding the derailment site. Fires burned with varying intensities for as long as 18 days; however, there were no explosions. The surrounding area was evacuated as a precaution.

Firefighters initially began fighting the fires that were burning at the buildings surrounding the derailment site. When the derailed tank cars contents were determined, the potential for a boiling liquid expanding vapor explosion (BLEVE) from the tank cars forced the firefighters to fall back to a safe distance. Some firefighters even abandoned their hoses in the surrounding streets demonstrating the gravity of the threat.⁴

⁴ Burke, Robert. "Weyauwega Wisconsin Propane Fire," http://www.firehouse.com/training/hazmat/studies/1996/07_wi.html July, 1996.

Over the next 14 days, responders focused on stabilizing the burning and damaged tank cars. This included “hot tapping” several cars to remove any liquid contents to a burn pit where it could be safely burned off. In order to prevent a BLEVE from any of the tank cars, this slow process of removing the contents and deliberately burning it off in a controlled condition was the chosen approach.

There were no injuries to emergency responders or residents directly resulting from the derailment. A diagram of the placement of the derailed cars, reproduced from the original NTSB accident report, is provided in Figure 2, below.

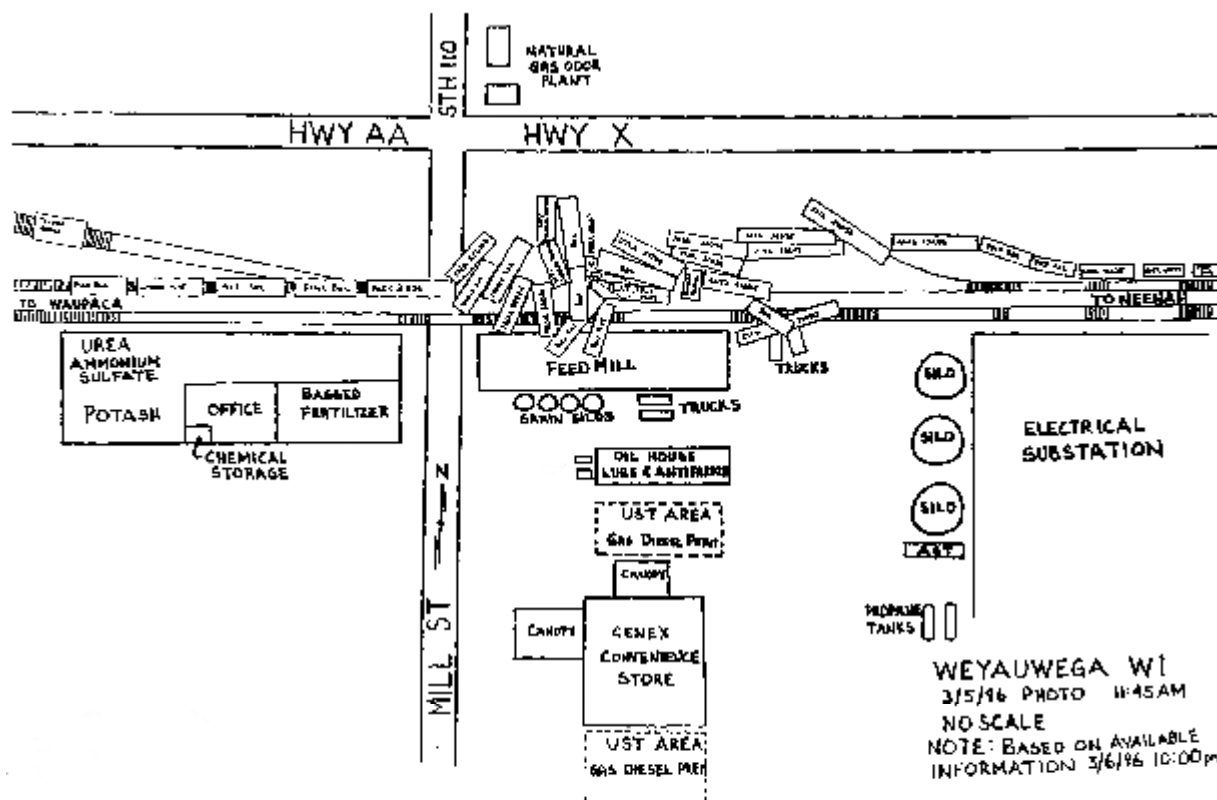


Fig. 2. Train derailment diagram

Placement of a spent fuel transportation package

Figure 3 represents a portion of the original derailment diagram and provides a detail of the derailed configuration, with the LPG and propane tank cars numbered.

In Figure 3, the red tank cars were breached and ignited shortly after the derailment, the yellow cars were leaking from valves or seals and may eventually have been involved in the fire, and the light blue cars were ones that were not breached at the time of the derailment. The photograph in Figure 1 was taken from a helicopter located northwest of the diagram presented in Figure 3. As a point of reference, the silo in the lower right hand corner of Figure 3 is the first silo in the row of silos on the left side of Figure 1, just behind the rail line.

Table I. Spent Fuel Casks Analyzed in the Howard Street Tunnel Fire Study

Cask Model	HI-STAR 100	TN-68	NAC-LWT ⁵
	(Package on rail car)		
Transport Mode	Rail	Rail	Truck/Rail
Loaded Weight lbs (kg)	277,300 (125,781)	260,400 (118,116)	52,000 (23,587)
Decay Heat Load (kW)	20	21.2	2.5
Contents	24 PWR ⁶ assemblies	68 BWR ⁷ assemblies	1 PWR assembly
Cask Closure Design Features	Bolted Overpack, Inner Welded Canister	Bolted Lid with O-rings	Bolted Lid with O-rings

The cask designs were chosen because they represented shipping cask designs that have been or would likely be used in large shipping campaigns. The NAC-LWT truck cask was modeled inside an ISO shipping container, representing the actual shipping configuration that is used in the Department of Energy’s rail shipments of foreign research reactor fuel with this cask.

Figure 4 depicts the positions of the rail cars used to model the Howard Street tunnel fire scenario. The flatbed rail car containing the SNF package was assumed to be as close as possible to the fire location, based on the arrangement of rail cars required to conform to DOT regulations regarding transport of hazardous materials and radioactive materials on a single train. The tunnel cross-section is too narrow to allow derailed cars to slide past one another, so that at a minimum, there would be one rail car length between the tanker and the flatbed carrying the SNF package. A flatbed car was assumed to provide this buffer, resulting in the arrangement shown in Figure 4, consisting of the tank car, an empty flatbed car, and the flatbed with a spent nuclear fuel (SNF) cask. The top image of Figure 4 shows the required spacing of the rail cars. The middle image depicts the fire beginning at the site of the tank car leak, and the bottom image shows a conceptual diagram of the fully developed tunnel fire.

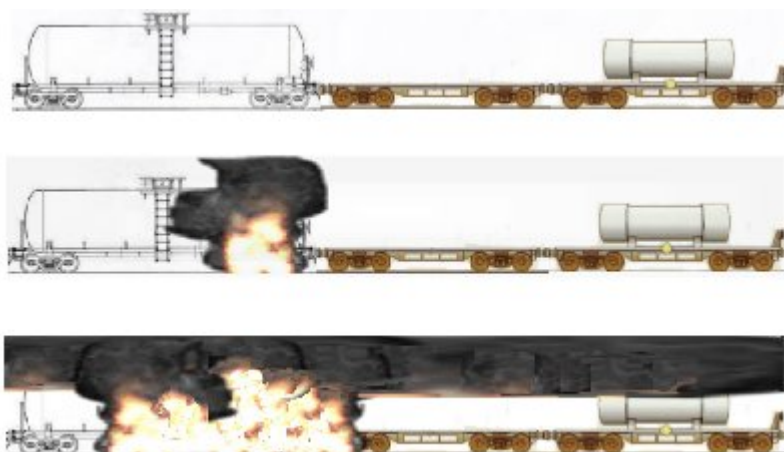


Figure 4. Representation of a Spent Fuel Cask in the Howard Street Tunnel Fire Scenario.

⁵ Package within an ISO container for rail transport

⁶ Pressurized Water Reactor (thermal design basis most limiting fuel and maximum decay heat loading assumed for each cask)

⁷ Boiling Water Reactor (thermal design basis most limiting fuel and maximum decay heat loading assumed)

USNRC staff evaluated the radiological consequences of the package responses to the Howard Street tunnel fire. The results are summarized in Table II. The results of these evaluations strongly indicate that neither spent nuclear fuel (SNF) particles nor fission products would be released from a spent fuel shipping cask involved in a severe tunnel fire such as this. None of the three cask designs analyzed for the Baltimore tunnel fire scenario (HI-STAR 100, TN-68, or NAC LWT) experienced internal temperatures that would result in rupture of the fuel cladding. Therefore, radioactive material (i.e., SNF particles or fission products) would be retained within the fuel rods.

For this fire, there would be no release from the HI-STAR 100, because the inner welded canister remains leak tight and all seals remain intact. The potential releases calculated for the TN-68 rail cask and the NAC LWT cask as a consequence of exceeding seal temperature limits, indicate that any potential release (driven by high internal package temperatures and assumed seal failure) of CRUD particles⁸ from either cask would be very small - less than an A₂⁹ for radionuclides of greatest concern. Releases of this magnitude would not pose a significant health risk to either first responders or the public. Similarly, none of these casks in this fire scenario would experience significant degradation of neutron and gamma shielding, and would not exceed radiation dose rate limits for accident conditions.

Cask Model	Potential Releases (calculated)	Comments	Number of A₂'s released
HI-STAR 100	None	Releases prevented By Inner Canister.	0
TN-68	3.4 Ci of ⁶⁰ Co	Potential release due to CRUD. Cladding remains intact.	0.3
NAC-LWT	0.02 Ci of ⁶⁰ Co	Potential release due to CRUD. Cladding remains intact.	0.002

EFFECTIVENESS OF CURRENT US RAIL PRACTICES AND PACKAGE SAFETY REQUIREMENTS

The NRC has a long history of examining the risks of transporting radioactive materials, including spent nuclear fuel, on the roads and rails of the United States (US). The NRC reviewed the Howard Street tunnel fire of 2001 to determine the potential effects this accident could have had on specific spent fuel transportation package designs, and to further confirm the effectiveness of the current transportation regulations found in 10 CFR Part 71.[2] Based on the results of the NRC review of the Howard Street tunnel fire, the NRC expanded its examination of severe accidents to include historic rail accidents that involved hazardous materials and long duration fires. These efforts were largely completed when, in February 2006, the National Academy of Sciences (NAS) issued a report entitled: "Going the Distance? The Safe Transport of Spent Nuclear Fuel and High Level Radioactive Waste in the United States," [5] which concluded that current package performance standards in 10 CFR Part 71 [2] were adequate to ensure package containment effectiveness over a wide range of transportation accidents, including most credible accident conditions, but recommended an evaluation of whether current package performance standards bound accidents involving very long-duration, fully engulfing fires. The staff's efforts prior to and since the release of the NAS report have been in line with the recommendations contained in the report.

⁸ CRUD particles available for release were limited to 15% of the total CRUD available (per spent fuel rod) and a deposition factor of 0.9. Further details of this calculation can be found in Chapter 8 of Reference [1].

⁹ The actual amount of a particular material that constitutes an A₂ quantity depends on the radiological properties of the material. Appendix A of 10CFR71 defines the A₂ quantities for a large number of different materials in Table A-1, and specifies methods for calculating the appropriate value for any material not listed in the table.

The NRC staff's review of accidents involving hazardous materials and long duration fires on railroads and, specifically, in rail tunnels, has revealed that these accidents occur with extremely low frequency. The staff also concluded that there were generally two types of accidents that occurred on rail lines in the US, derailments and fires that occurred on open rails and those that occurred in tunnels, with the tunnel fires generally being the more severe.

For derailments and fires that occurred in the open, the mitigating factors of proximity, fuel properties, and emergency response time, as discussed previously in this paper, provide a further protection, above and beyond the package regulations, for rail shipments of spent nuclear fuel. For the derailments studied, the separation requirements in DOT regulations would prevent the close proximity of a spent fuel transportation package (were one to be shipped on a train that also was carrying hazardous, flammable, or combustible materials) to a severe fire, such that the transportation package would be fully engulfed in the fire. In general, the types of flammable or combustible hazardous materials that are shipped on rails in the US are in gaseous form and, if ignited, tend to burn back to the source (such as a ruptured tank car) and will not form a "pool" type fire that could present the most severe challenge to a transportation package.

Derailments in tunnels that involve long duration fires have the potential to be more severe, in that the mitigating factors discussed above may not assist in limiting the duration or severity of a fire in a tunnel. While the proximity of a spent fuel transportation package to a severe fire may still be limited due to separation, the "oven effect" induced by the heating of the tunnel walls could present a more severe overall thermal environment to the package. The rail beds in tunnels can be less porous than those of open rails, and therefore, increase the potential for "pooling" of liquids if there is a breach of a railcar in a tunnel. Finally, because of the geometry and length of a tunnel, first responders may find it difficult to directly access and attempt to extinguish any fires that develop due to a derailment. Limited access was a major factor in the duration of the Howard Street tunnel fire. Firefighters were not able to gain direct access to the burning tripropylene tank car to commence firefighting activities.

As a further safeguard against tunnel fire exposures, the Association of American Railroads enacted, at the recommendation of the NRC, a "no-pass" rule for single bore dual-track rail tunnels.[6] The rule specifies that trains carrying tank cars containing hazardous materials, such as flammable or combustible liquids, and trains carrying SNF or HLW may not pass one another within the same tunnel. This is an operational control that further reduces the likelihood of a severe tunnel fire involving a spent nuclear fuel transportation package, while having a minimal impact on railroad operations.

CONCLUSIONS

The risk of a spent fuel transportation package being involved in a fully engulfing fire is extremely small based on the historically low frequency of rail accidents involving severe fires.

Current US regulations for the design of spent fuel transportation packages, coupled with the safety requirements and operating practices in place for rail shipments, provide a high degree of assurance that NRC certified spent fuel packages would survive severe rail fires without a significant release of radioactive material.

REFERENCES

1. NUREG/CR-6886, "Spent Fuel Transportation Cask Response to the Baltimore Tunnel Fire Event," US Nuclear Regulatory Commission, November 2006.
2. Title 49, Code of Federal Regulations, Subchapter C, *Hazardous Materials Regulations*, Oct. 1, 2008, United States Government Printing Office, Washington, D.C
3. 10 CFR 71. Jan. 1, 2009. *Packaging and Transportation of Radioactive Material*. Code of Federal Regulations, U.S. Nuclear Regulatory Commission, Washington D.C.
4. Mibeck, B., et. al., "Weyauwega Derailment – Tank Car inspection Field Notes," National Transportation Safety Board/Federal Railroad Administration, March, 1996.
5. "Going the Distance? The Safe Transport of Spent Nuclear Fuel and High Level Radioactive Waste in the United States," The National Academies Press, Washington, D.C., February, 2006.
6. Circular No. OT-55-I (CPC-1174), American Association of Railroads, July 17, 2006.