Impacts of a Severe Road Tunnel Fire on Transportation of Spent Nuclear Fuel - 11583

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ABSTRACT

In October 2007 just north of Los Angeles, California, a chain-reaction accident involving numerous tractor trailers in the I-5 "Newhall Pass" truck bypass tunnel occurred. This accident also involved an intense fire that damaged the concrete walls of the tunnel and required the tunnel to be closed for repairs. The objective of the work described in this paper was to determine the maximum exposure temperature in the tunnel and evaluate the conditions likely to be found in this fire. The study included analyses of material recovered from the incinerated vehicles and a simulation of the Newhall Pass tunnel fire using the Fire Dynamics Simulator code developed by the National Institute of Standards and Technology. A discussion of the results of this study as well as the potential implications of this accident for the transportation of spent nuclear fuel by truck will be provided.

NOMENCLATURE

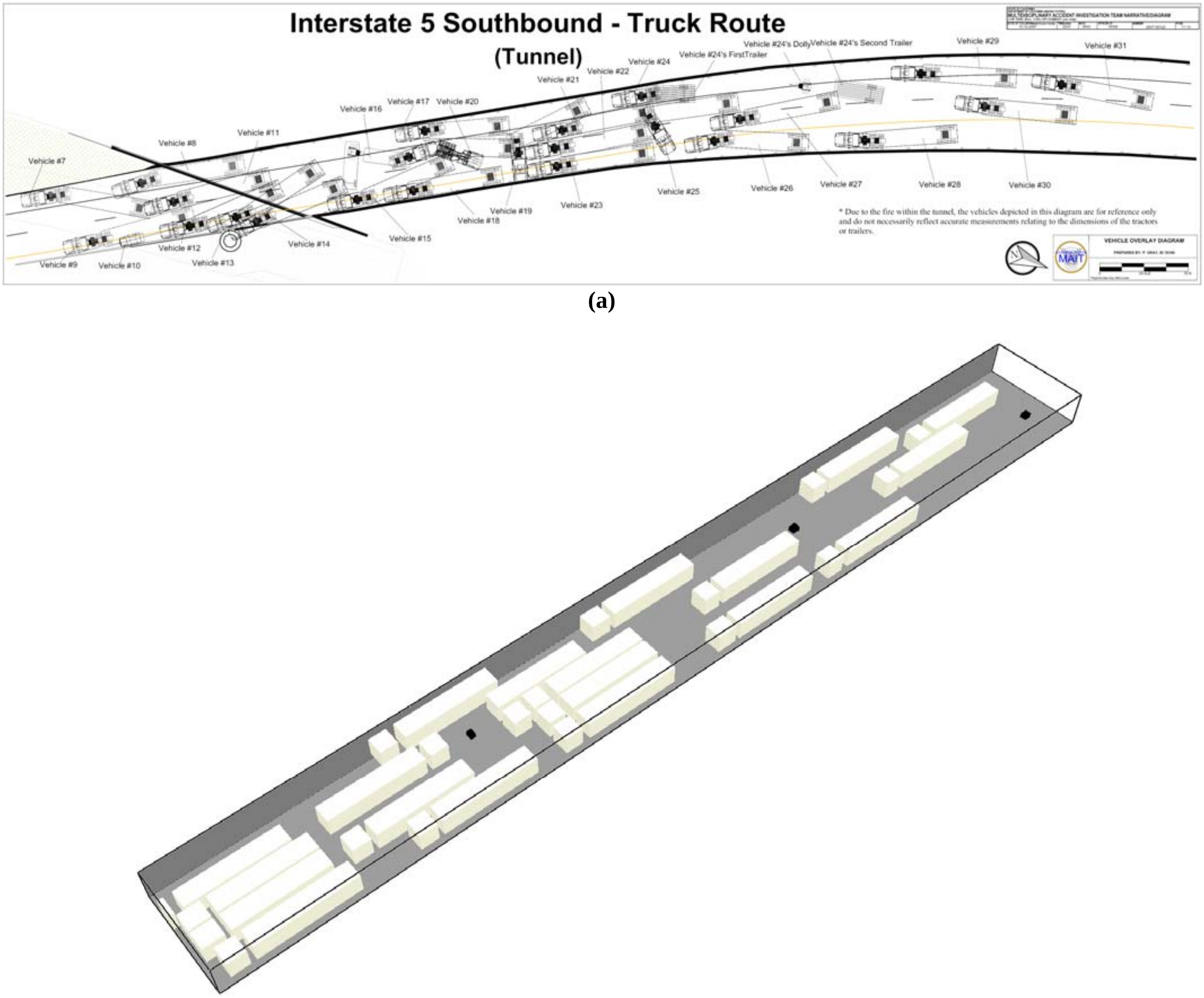
CHP – California Highway Patrol
FDS – Fire Dynamics Simulator
NRC – United States Nuclear Regulatory Commission
SwRI® – Southwest Research Institute®

INTRODUCTION

The USNRC is one of the regulatory authorities that oversee the packaging and transportation of radioactive materials. Under current U.S. regulations, a spent nuclear fuel (SNF) transportation package must be designed to withstand a hypothetical accident condition, which includes dropping, crushing, puncture, thermal excursion, and immersion in water. This paper focuses on the analyses of a tunnel fire to support the thermal excursion evaluation. The current USNRC regulations indicate that an 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 excursion.

The Newhall Pass tunnel fire occurred on October 12, 2007, at approximately 10:40 p.m. near Santa Clarita, California. The tunnel fire was the result of a truck exiting the tunnel, losing control, and hitting a concrete median barrier. This led to a chain reaction, and roughly 33 commercial vehicles and 1 passenger vehicle were involved in a multivehicle pileup, which spanned the full length of the tunnel (See Figure 1a). Of the 34 vehicles, only 25, including the passenger vehicle, were involved in the fire. The other nine vehicles were only involved in collisions that occurred outside the tunnel. The accident occurred in the Newhall Pass tunnel, a reinforced concrete boxed girder, which was built in 1971. The winds in this location tend to be southerly, which led to the spread of the fire into the tunnel. It was reported that the fire appeared to emanate from both ends of the tunnel within 15 minutes of its start. By 12:00 p.m., October 13, 2007, the fire was completely out on the south portion of the tunnel, but was still smoldering.

The study of the Newhall Pass fire included an evaluation of the thermal conditions (temperatures and flow of combustion gasses) that occurred both by analyzing materials exposed to the tunnel fire and by developing a computational model of the fire. Materials analyses were conducted on samples collected from 5 of the 25 vehicles involved in the fire. The objective of the materials analyses work was to evaluate the characteristics of the sampled components exposed to this tunnel fire and estimate an approximate range of temperatures to which these components were exposed. This tunnel fire was also modeled (See Figure 1b) using the computational fluid dynamics code FDS Version 5[2,3] to calculate the gas and wall temperatures in the tunnel as the fire progressed. The geometry of the tunnel, amount of combustible materials, and weather conditions were considered in the modeling effort. The information from the materials analyses will be used as a consistency check with the fire model results and to provide additional support for temperature range estimates of the Newhall Pass tunnel fire. While a significant amount of modeling has been completed, the results are considered preliminary and, as a result, will not be discussed in detail in this paper.



* Due to the fire within the tunnel, the vehicles depicted in this diagram are for reference only and do not necessarily reflect accurate measurements relating to the dimensions of the tractors or trailers.

(a)

(b)

Fig. 1. Newhall pass tunnel geometry (a) provided by multidisciplinary accident investigation team (courtesy of CHP) and (b) fire dynamics simulator model approximation

INCINERATED TRUCK SAMPLE ANALYSES

In cooperation with CHP, staff from SwRI® accessed the vestiges of five vehicles incinerated in the Newhall Pass tunnel fire which were held in vehicle impound lots. During the onsite examination of the impounded vehicles, a variety of materials were acquired, including aluminum alloys, copper, brass, and steel. The metallic samples were specifically selected for their use in quantifying the thermal excursion of the fire incident.

Nonferrous Alloy Specimens

A differential scanning calorimeter (DSC) was used to determine the incipient melting temperature of the nonferrous alloys (i.e., aluminum, copper, and brass) in this study. For the samples that were observed to have melted, the DSC measurement provided a lower bound that the material was known to have reached. If the material had not melted, the DSC measurement provides an upper bound that the material was known to have not reached. Aluminum samples were one of the most prevalent samples obtained because many truck components are composed of aluminum. The measured solidus temperatures, representing the onset of melting, are shown in Table I for aluminum truck samples.

TABLE I. Melting Point Determinations of Aluminum Samples Recovered From Trucks

Sample Identification	Melting Point, °C (°F)	Sample Identification	Melting Point, °C (°F)
Truck 9 #1 (melted)	565.0 (1,049.0)	Truck 14 #4 (melted)	654.3 (1,209.7)
Truck 14 #1	661.0 (1,221.8)	Truck 18 #1 (melted)	563.1 (1,045.6)
Truck 14 #2 (melted)	679.4 (1,254.9)	Truck 18 #2 (melted)	571.0 (1,059.8)
Truck 14 #3 (melted)	558.1 (1,036.6)		

Copper wire was found on the vehicles, as it is typically present in automotive electrical systems.[7] Copper was collected from the battery cable wiring and brake light fixtures. The smaller gauge brake light wiring would be expected to provide an excellent indication of the surrounding ambient temperature because the low thermal mass responds more rapidly to changes in temperature under applied heat. In addition to copper, there are many brass automotive components representing a range of copper and zinc alloy compositions.

For brass, there is a wide range of compositions with corresponding variations in solidus temperatures. With one exception, the samples collected showed no signs of incipient melting, which indicates that none of their respective solidus temperatures were achieved in the fire. The single exception was observed with Truck 17 Sample #1, where one inside ferrule of a fitting was observed to have partially melted. The opposite side of the fitting had the same internal ferrule, but did not have any indications of incipient melting. The melting temperature determinations by calorimetry indicated that these components had similar incipient melting temperatures, and therefore the difference in melting behavior was likely due to a thermal gradient. The results of these and other DSC measurements for copper-based alloys are shown in Table II.

TABLE II. Melting Point Determinations of Copper-Based Samples Recovered From Trucks

Sample Identification	Melting Point, °C (°F)	Sample Identification	Melting Point, °C (°F)
Truck 14 #5	1,066.7 (1,952.1)	Truck 17 #1 (melted)	884.2 (1,623.6)
Truck 14 #6	1,072.3 (1,962.1)	Truck 17 #2	929.5 (1,705.1)
Truck 14 #7	921.2 (1,690.2)	Truck 18 #3	1,064.2 (1,947.6)
Truck 14 #8	1,066.8 (1,952.2)	Truck 18 #4	914.2 (1,677.6)

Ferrous Alloy Specimens

The remaining ferrous alloy samples from the incinerated vehicles comprised steel and cast iron. None of the ferrous alloys had signs of incipient melting. Solidus temperatures for cast iron are in the range of 1,177 to 1,260 °C (2,151 to 2,300 °F).[8,9] Carbon steel materials have a melting temperature of approximately 1,516 °C (2,761 °F). Because there was rarely any melting of brass and no melting of copper observed in the specimen set, it is unlikely that the tunnel fire temperatures were hot enough to melt the ferrous alloys. However, the solid-state transformations in steel, with corresponding changes in hardness, provide a temperature exposure metric.

Ferrous alloy specimens, in the form of graded bolts, were analyzed by hardness measurements and optical metallography to establish the maximum thermal excursion to which they were subjected. None of the bolts or any other ferrous alloy vehicle components indicated melting. Hence, the analyses of the bolts focused on microstructural phase changes and the corresponding effect on hardness, as these quantities are influenced by solid-state reactions, which occur at lower temperatures.

The hardness data obtained from the incinerated vehicle samples were compared to the values obtained from a set of reference specimens. The reference specimens that were heat treated and compared to the vehicle bolts were all new, commercially purchased Grade 5 bolts. All of the new bolts had vendor stamps of JH, TY, or arrows (as symbols). The heat treatment and subsequent hardness measurements of the reference specimens were utilized to produce a profile of hardness values as a function of thermal exposure. The hardness values obtained from the vehicles' graded bolts were correlated to the hardness profile of the reference specimens to ascertain approximated fire temperatures at each bolt location. In addition to the vendor stamping on the bolts, they were also stamped with markings consistent with SAE Grade 5,[10] which specifies a minimum of 92,000 psi (630 MPa) yield stress; 120,000 psi (830 MPa) minimum tensile stress; and a core Rockwell hardness of C25 to C34.[10] The bolts were sectioned, and the hardness was measured using a Tukon 2100B hardness tester. The as-collected samples had a core hardness that varied from Rockwell B78 to B101 (approximately Rockwell hardness C0 to C24), as shown in Table III. The hardness for these bolt samples collected from the incinerated vehicles is well below specifications, indicating they had likely been heated well above the minimum tempering temperature, thereby reducing strength and hardness.

TABLE III. Hardness Measurements for Steel Fasteners Recovered From the Incinerated Trucks

Sample Identification	Hardness (Rockwell B)
9-01	78
14-04	101
18-02	90
18-03	91
27-01	85

The reference specimens that were heat treated and compared to the vehicle bolts were all new Grade 5 bolts. Measurements in the as-received condition, shown in Table IV, indicate that they were all within specifications having hardness values between Rockwell C28 and C31. The bolt samples were exposed to temperatures ranging from 400 to 1,000 °C (752 to 1,832 °F) for 2 hours. In addition to these tests, some additional samples were exposed to the temperatures 800 and 1,000 °C (1,472 and 1,832 °F) for either 1 or 4 hours. Samples exposed to temperatures above 400 °C (752 °F) were cooled to 400 °C (752 °F) prior to removal from the oven and allowed to air cool to room temperature.

The measured hardness value for the heat-treated reference samples is shown in Table IV and presented in Fig. 3. The effect of temperature on hardness is shown as a decreasing slope in this figure. Although there were some slight differences in the chemical composition of the three reference samples, the hardness curves as a function of temperature are very similar. The results suggest that an exposure to a temperature between 800 and 1,000 °C (1,472 and 1,832 °F) for 2 hours would result in a reduction of hardness similar to that observed for the as-collected condition of Truck Sample 9-01. The results also suggest that an exposure to temperatures of roughly 420, 670, 690, and 750 °C (788, 1,238, 1,274, and 1,382 °F) would similarly reduce hardness that was observed for the as-collected condition of Truck Samples 14-04, 18-03, 18-02, and 27-01, respectively.

TABLE IV. Hardness Measurements for Reference Steel Fasteners

Temperature and Heat Treatment Time	Reference Specimen Hardness (Rockwell B)		
	JH	TY	Arrow
As-received	> 102*	> 102*	> 102*
400 °C (752 °F) for 2 hours	> 102*	> 102*	> 102*
600 °C (1,112 °F) for 2 hours	96	97	98
800 °C (1,472 °F) for 1 hour	81	79	82
800 °C (1,472 °F) for 2 hours	83	81	80
800 °C (1,472 °F) for 4 hours	84	81	84
1,000 °C (1,832 °F) for 1 hour	82	78	84
1,000 °C (1,832 °F) for 2 hours	78	82	82
1,000 °C (1,832 °F) for 4 hours	74	80	82

*Fastener hardness values were converted to Rockwell C from Rockwell B to compare with untreated fasteners. Although conversion between Rockwell B and C scales reduces accuracy, this approach was necessary to compare values that span a wide range of hardness such as in the bolts analyzed in this study.[11]

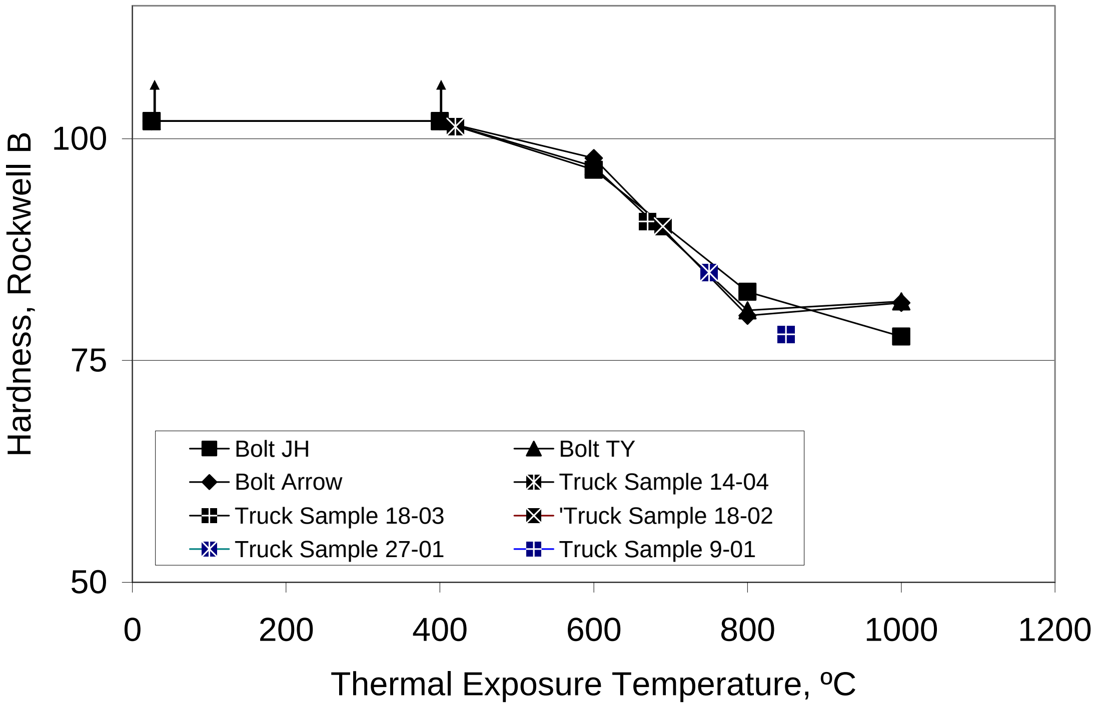


Fig. 3. Effect of exposure temperature on the hardness of truck samples and commercially available Grade 5 bolts

CONCLUSION

The objective of this work was to estimate the temperatures observed in the Newhall Pass tunnel during the October 2007 tunnel fire. Temperatures were estimated from materials analyses of samples taken from the incinerated vehicles. In addition to aluminum alloys, many copper-based alloys including brass were collected and analyzed. Almost all of the copper-based alloys showed no signs of incipient melting, except a melted brass ferrule indicated a tunnel temperature of 884 °C (1,623 °F) by the melting point analysis.

A fire model was developed to simulate the Newhall Pass tunnel fire. The model accounted for many of the conditions including tunnel geometry, vehicle geometry, fire sources, and local weather. The results of these simulations are preliminary and will be discussed in future papers.

ACKNOWLEDGMENTS

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