# The MacArthur Maze and Newhall Pass Fires and Their Implications for Spent Fuel Transport - 10536

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## ABSTRACT

In 2007, two severe transportation accidents, involving primarily long-haul tractor trailers, occurred in the State of California. In the first, which occurred in Oakland in the "MacArthur Maze" section of Interstate 580, a tractor trailer carrying gasoline impacted an overpass support column and burst into flames. The subsequent fire caused the collapse of the overpass onto the remains of the tractor trailer, due to the loss of strength in the steel exposed to the fire, in less than 20 minutes. The second incident was a chain-reaction accident involving several tractor trailers in the I-5 "Newhall Pass" truck bypass tunnel in Santa Clarita. This accident also involved an intense fire that damaged the concrete walls of the tunnel and required the tunnel to be shutdown for repairs. The US Nuclear Regulatory Commission (NRC) has studied both of these accidents to examine any potential regulatory implications related to the safe transport of spent nuclear fuel in the United States. This paper will summarize the work completed to date by the NRC on these accidents.

## NOMENCLATURE

Caltrans – California Department of Transportation
CHP – California Highway Patrol
NRC – United States Nuclear Regulatory Commission
SwRI® – Southwest Research Institute®

## BACKGROUND

The primary objectives of the work described in this paper were to assess the severity of the MacArthur Maze and Newhall Pass fires by evaluating the structural and other materials exposed to the fires and estimating the maximum temperatures experienced by those materials during the fire events. The NRC is currently evaluating these accidents in comparison to the hypothetical accident condition fire exposure defined in Title 10 of the Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material" [1] and assessing the potential impact of these types of accidents on radioactive material or spent nuclear fuel transportation packages. This work is ongoing, and may be presented in future papers.

### The MacArthur Maze Accident and Fire

The accident occurred on Sunday morning, April 29, 2007, in an area commonly known as the "MacArthur Maze", a network of connector ramps that merge highways I-80, I-580, and I-880 in Oakland, California. The fire that eventually led to the overpass collapse started at about 3:38 a.m. when a gasoline tanker truck carrying 32,500 liters [8,600 gallons] of gasoline crashed and caught fire. The tanker truck was heading south along I-880 at the time of the accident. While nearing the I-580 overpass, the vehicle rolled onto its side and slid to a stop on the 50-foot-high ramp connecting westbound I-80 to southbound I-880.

The main portion of the fire, fueled by the gasoline leaking from the tanker, spread along a section of the I-880 roadway. Some of the gasoline went through the scupper drain on I-880 and burned on the ground around an I-880 roadway support pillar. The fire on the I-880 roadway heated the steel girders on the underside of the of the I-580 overpass to temperatures where the steel strength was reduced and was insufficient to support the weight of the elevated roadway. The I-580 overpass collapsed onto the I-880 roadway about 17 minutes after the fire started, based on surveillance video taken from a water treatment plant adjacent to the highway interchange. An aerial photograph of the area with the accident site identified is shown in Figure 1 [2]. A photograph of the scene after the fire was extinguished is shown in Figure 2[1] [3].

[1] The transverse support locations for the elevated roadway are referred to as "Bents" in Figure 2.

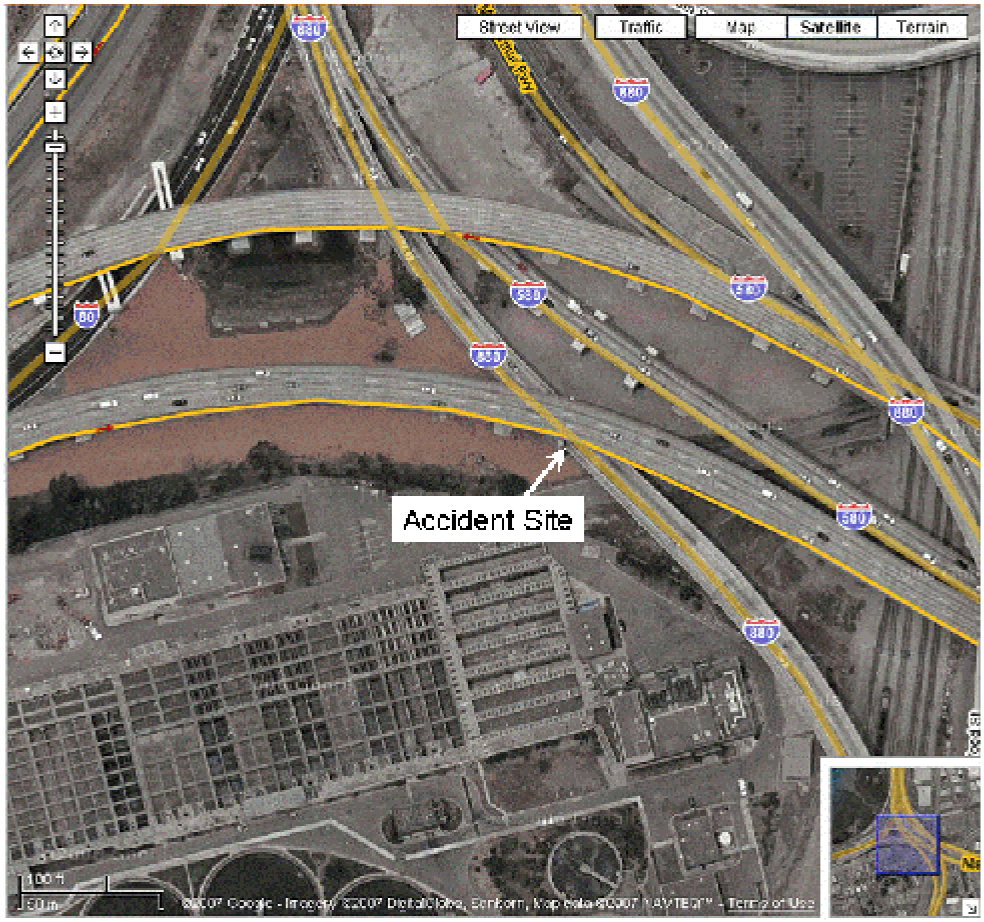


**Fig. 1. Aerial photograph of I-880 and I-580 Interchange**

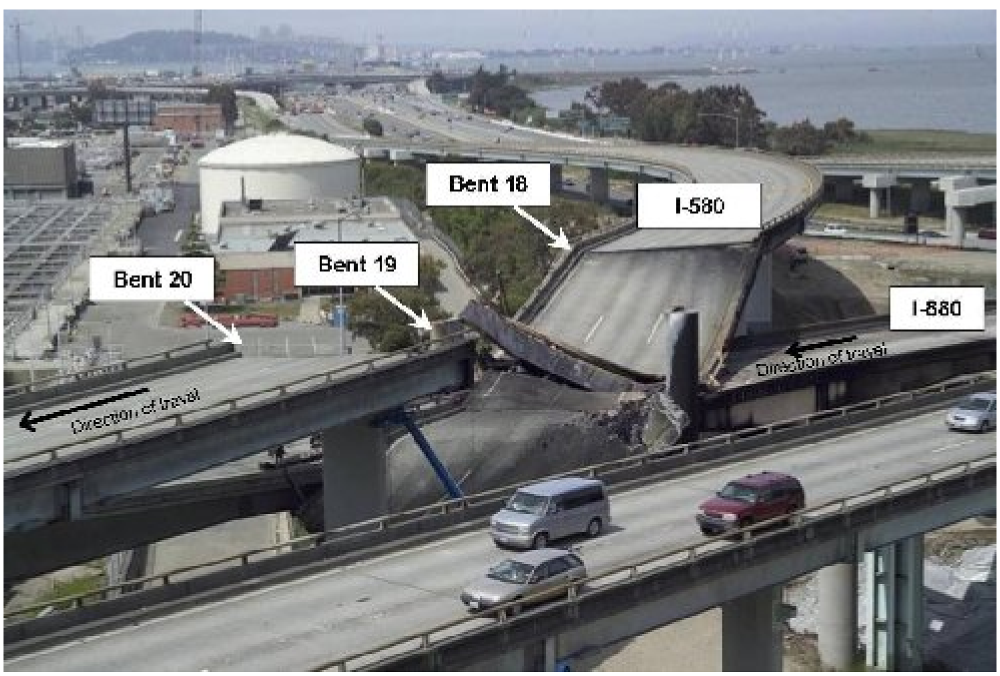


**Fig. 2. Postfire aerial view of the collapsed section of I-580 looking west. Picture from Caltrans http://www.dot.ca.gov/dist4/photography/images/070429.**

**The Newhall Pass Accident and Fire**

On October 12, 2007, a major fire occurred in the Newhall Pass tunnel near Santa Clarita, California at approximately 10:40 p.m. The Newhall Pass tunnel is part of the Interstate 5 southbound truck lane as it passes below Interstate 5 main lanes. The tunnel is a 165.8-m [544-ft] long reinforced concrete boxed girder, which was built in 1971. The tunnel fire was a result of a truck accident that led to a 34-vehicle pile-up in and around the Newhall Pass tunnel. One of the vehicles caught on fire and ignited the other vehicles in the tunnel. It was reported that the fire appeared to emanate from both ends of the tunnel within 15 minutes of its start (See Figure 3). An aerial map of Newhall Pass tunnel is shown in Figures 4 and 5.

**(a)** **(b)**

**Fig. 3. Images of Commercial Vehicles on Fire Outside Tunnel Exit. Photos by Gene Blevins/LACOFD/Photo.**

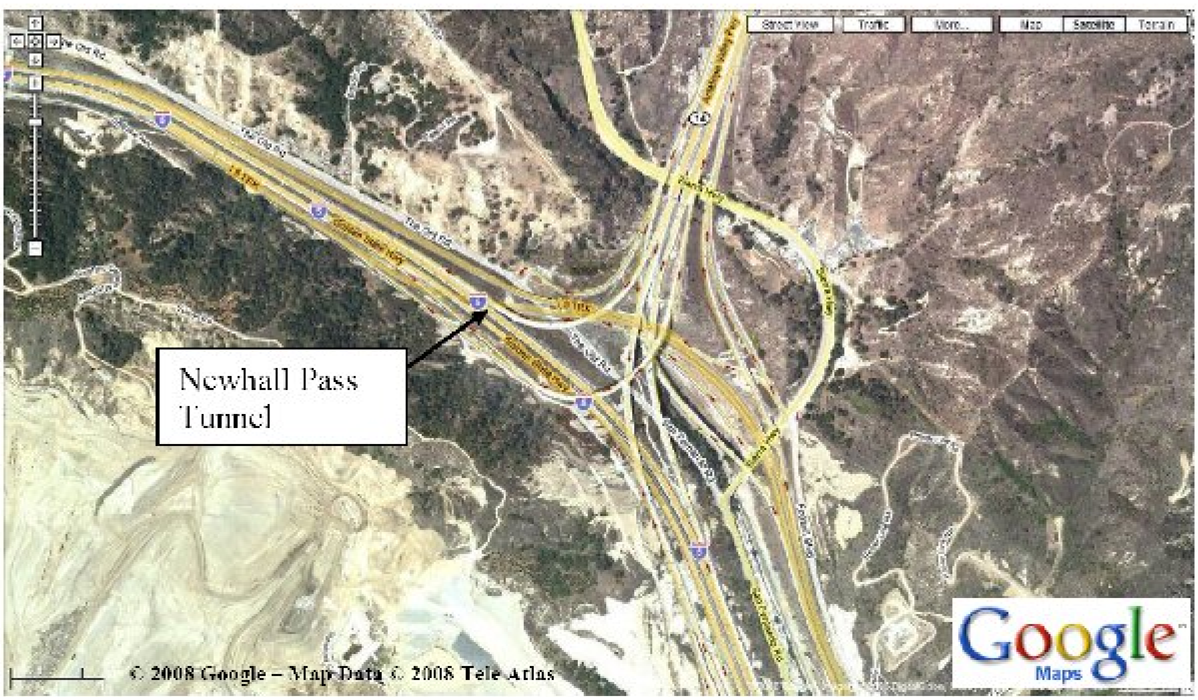


**Fig. 4. Aerial Photograph of Interstate 5 and Highway 14 Interchange**


**Fig. 5. Aerial Photograph of Interstate 5 and Highway 14 Interchange. The Accident Initiated on the Exit (Southwest Side) of the Tunnel.**

## DETERMINING FIRE TEMPERATURES: THE MACARTHUR MAZE FIRE

### Examining Physical Evidence

Initial media reports of the MacArthur Maze accident cited sources at the scene as estimating that the fire reached temperatures as high as 1,650°C [3,000°F]; however, to the NRC's knowledge, no direct temperature measurements were taken of the fire.

Review of the extensive photographic documentation compiled by Caltrans during the demolition and repair of the overpass, as well as examination of the I-580 overpass girders after the demolition, revealed no indications that any of the steel girders were exposed to temperatures where melting would be expected. Although the actual melting temperatures of steel alloys, including carbon steels, is composition dependent, low carbon steels have melting temperatures near 1,515°C [2,760°F]. For comparison, pure iron has a slightly higher melting temperature of 1,538°C [2,800°F]. Because no melting of the structural steel was observed, the determination of the maximum temperatures to which the girders were exposed was performed using other information. Other items that aided in determining the fire temperature included melting of alloys used on the tanker truck, spalling of concrete, damage to paint, and solid-state phase transformations in the steel girders. Spalling of the concrete was observed on the surface of the I-880 roadbed, the actual extent of which was measured by Caltrans. Damage to the paint of the steel girders also served as a useful indication of temperature especially with the extensive photographic documentation available from Caltrans. NRC and SwRI staff collected and analyzed material samples from the steel girders and the tanker truck to estimate exposure temperatures.

### Samples of the MacArthur Maze (I-580 Overpass)

Samples of steel girders from the collapsed I-580 overpass were collected and metallurgical analyses were conducted to determine the effect of the fire temperature on the microstructure of the materials. To minimize the effects of obtaining samples, metallurgical sections were prepared using a liquid-cooled saw to perform coarse cutting. Specimens for analysis were obtained from material that was at least 50 mm [2 in] from torch cut edges to avoid including any material that was altered by the high temperature cutting operation. It was determined that the altered material from the cutting operation should be confined to a much smaller distance from the torch cut edge.

The approximate locations of the samples collected from the collapsed structure are shown in Figure 6 [3]. Table I provides a list and a brief description of the samples that the staff collected during a visit to the accident site in June, 2007.

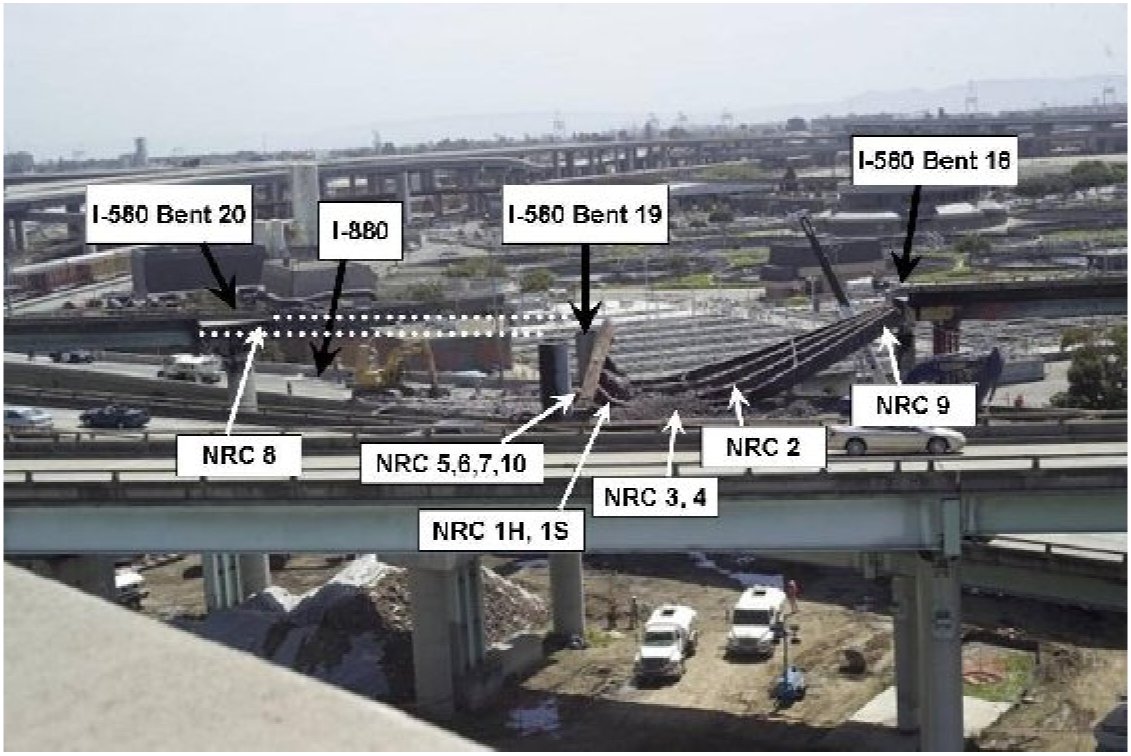


**Fig. 6. View of damage during demolition looking southwest. Bent 18, 19, and 20 and approximate locations of collected specimens are indicated. Dotted lines represent pre-accident overpass structure that was demolished and removed prior to this photograph. Original picture from Caltrans website**
http://www.dot.ca.gov/dist4/photography/images/070430/index2.html

**Table I. Description of Samples Collected**

| Sample Number | Description |
|---|---|
| NRC 1H | Plate Girder 3 at Bent 19 end with rivet holes. Specimen did not contain weld metal. |
| NRC 1S | Plate Girder 3 with stiffener near Bent 19. Specimen contained weld metal. |
| NRC 2 | Plate Girder 4 with Butt Weld. Specimen contained weld metal. |
| NRC 3 | Plate Girder 5 likely located between Bent 18 and Bent 19 with stiffener heavy distortion. Specimen contained weld metal. |
| NRC 4 | Plate Girder 5 likely located between Bent 18 and Bent 19 with stiffener medium distortion. Specimen contained weld metal. |
| NRC 5 | Box Beam Cap 7 lower plate with side and weld. Specimen contained weld metal. |
| NRC 6 | Plate Girder found attached to Box Beam Cap 8 with reduction in area. |
| NRC 7 | Rivet head located in Box Beam Cap 8. |
| NRC 8 | Plate Girder 10 Near Bent 20 Web and plate with weld. Specimen contained weld metal. |
| NRC 9 | Plate Girder 12 with stiffener near Bent 18. Specimen contained weld metal. |
| NRC 10 | Flakes peeled off of plate girder angles on Box Beam Cap 8. |

**Analysis of As-Received Samples**

The metallurgical sections were placed in epoxy mounts. The sections were prepared using progressively finer grinding papers followed by polishing. The polished sections were then etched using nital (a mixture of ethanol and nitric acid). Etched samples were immersed in alcohol to prevent corrosion by either atmospheric exposure or by residual amounts of etchant retained within pores in the sample.

It was determined that the examination of welds in the girder sections could provide information on the temperature of the steel structure during the fire. Given the size and materials of construction, the welds in the girders would not be expected to have undergone postweld heat treatment. Therefore, in the original 'as-built' state, the microstructure of the welds would exhibit characteristics of as-deposited weld metal, which is typically a dendritic microstructure consisting of primarily ferrite with carbide precipitates, whereas the plate sections would be expected to have an equilibrium structure consisting of ferrite and pearlite based on the phase diagram for Iron-Carbon alloys. While specific information on the kinetics of low carbon steels is not readily available, heating of the as-deposited weld metal to sufficiently high temperatures should result in a phase transformation to an equilibrium microstructure consisting of pearlite and ferrite.

A summary of the analysis results for selected samples is shown in Table II. Efforts were focused on the analysis of girder sections that were believed to be located close to the fire (i.e., near Bent 19) as well as samples that were known to be in much cooler locations such as near Bent 18. For example, Samples NRC 3 and NRC 4 were collected from Plate Girder 5, which was buckled during the fire. Sample NRC 3 was likely located closer to Bent 19 compared to Sample NRC 4.

**Table II. Results of Microstructure Examination from Collected Samples**

| NRC Sample Number | Description | Results |
|---|---|---|
| NRC 1S | Plate Girder 3 with stiffener near Bent 19. Specimen contains weld metal. | Weld is as-deposited weld metal consisting of a dendritic microstructure with columnar and equiaxed grains. Some pearlite is also present. Web and plate are pearlite and ferrite. |
| NRC 2 | Plate Girder 4 with butt weld. Specimen contains weld metal. | Weld is pearlite and ferrite. Plate is pearlite and ferrite. |
| NRC 3 | Plate Girder 5 likely located between Bents 18 and 19 with stiffener heavily distorted. Specimen contains weld metal. | Weld is pearlite and ferrite. Plate and stiffener are pearlite and ferrite. |
| NRC 4 | Plate Girder 5 likely located between Bents 18 and 19 with stiffener medium distortion. Specimen contains weld metal. | Weld is pearlite and ferrite. Plate and stiffener are pearlite and ferrite. |
| NRC 5 | Box Beam Cap 7 lower plate with side and weld. Specimen contains weld metal. | As-deposited weld metal with a dendritic microstructure with columnar and equiaxed grains; web and plate are pearlite and ferrite. |
| NRC 8 | Plate Girder 10 near Bent 20. Web and plate with weld. Specimen contains weld metal. | Weld is as-deposited weld metal with dendritic microstructure with columnar and equiaxed grains. Web and plate are pearlite and ferrite. |
| NRC 9 | Plate Girder 12 with stiffener near Bent 18. Specimen contains weld metal. | Weld is as-deposited weld metal with dendritic microstructure with columnar and equiaxed grains. Plate and stiffener are pearlite and ferrite. |

As indicated above, both of these samples (NRC 3 and NRC 4) showed a transformation of the weld material due to exposure to higher temperatures.

**Analysis of Thermally Exposed Specimens**

When the samples were collected, it was recognized that the microstructures of the welds may be a useful indication of temperature. Sample NRC 9 was significantly larger than the other specimens so that a sufficient sample was available on which to conduct thermal exposures to determine the effect of exposure conditions on the microstructure of the welds. Multiple specimens were sectioned from the sample and exposed in an oven at temperatures ranging from 550 to 900°C [1,022 to 1,652°F] for a period of 3 hours followed by cooling in laboratory air. Table III shows the thermal exposure conditions and the results of the analysis.

**Table III. Microstructure Analysis of Thermally Exposed Specimens from Sample NRC 9.**

| Specimen Number | Thermal Exposure Temperature | Microstructure |
|---|---|---|
| NRC 9-1 | None | As-deposited weld metal with dendritic and equiaxed grains |
| NRC 9-2 | 550°C [1,022°F] | As-deposited weld metal with dendritic and equiaxed grains |
| NRC 9-3 | 600°C [1,112°F] | As-deposited weld metal with dendritic and equiaxed grains |
| NRC 9-4 | 650°C [1,202°F] | As-deposited weld metal with dendritic and equiaxed grains |
| NRC 9-5 | 700°C [1,292°F] | As-deposited weld metal with dendritic and equiaxed grains |
| NRC 9-6 | 750°C [1,382°F] | As-deposited weld metal with dendritic and equiaxed grains |
| NRC 9-7 | 800°C [1,472°F] | Partially transformed with dendritic and equiaxed grains and small regions of pearlite |
| NRC 9-8 | 850°C [1,562°F] | Mostly transformed weld metal with significant ferrite with pearlite |
| NRC 9-9 | 900°C [1,652°F] | Fully transformed microstructure consisting of ferrite with pearlite |

It is apparent that no transformation of the weld occurred at temperatures of 750°C [1,382°F] or less. At a temperature of 800°C [1,472°F], the microstructure of the weld is mainly dendritic, but some small amount of pearlite is also present. In Specimen NRC 9-8, exposed at 850°C [1,562°F], the microstructure contains more pearlite but is not fully transformed. After exposure to 900°C [1,652°F], the weld is fully transformed to a ferrite and pearlite microstructure. The microstructure of the welds in the specimens exposed to 850 or 900°C [1,562 or 1,652°F] appears to be similar to the microstructures observed in welds in specimens taken from Samples NRC 3 and NRC 4. This provides additional support to the exposure temperatures postulated for these samples.

**Analysis of the Tanker Truck Samples**

In March, 2008, staff from SwRI® and NRC inspected the tanker truck involved in the accident and collected selected samples for analysis. A variety of materials were collected including glass, aluminum alloys, steel, copper, brass, and stainless steel. Descriptions of the samples are shown in Table IV. Photographs of the truck remains are shown in Figure 7.

**Table IV. Description of Collected Tanker Truck Samples**

| Sample Identification | Description |
|---|---|
| Truck Sample 1 | Front tire cord from left side of vehicle |
| Truck Sample 2 | Tire cord from #5 axle on right side of vehicle |
| Truck Sample 3 | Brake pad located near rear of vehicle |
| Truck Sample 4 | Rim component sample from #5 axle |
| Truck Sample 5 | Spring located near rear of truck |
| Truck Sample 6 | Large bolts (3) located on frame and near engine |
| Truck Sample 7 | Grade 5 bolt located on frame |
| Truck Sample 8 | Copper wire ground strap located on frame |
| Truck Sample 9 | Copper wire battery cable |
| Truck Sample 10 | Copper wire electrical system wiring located on frame and melted aluminum |
| Truck Sample 11 | Fitting with brass located on engine |
| Truck Sample 12 | Bolt from engine passenger side with steel wire and melted aluminum |
| Truck Sample 13 | Aluminum screen from radiator |
| Truck Sample 14 | Aluminum rim from dual wheel axle |
| Truck Sample 15 | Aluminum tank section |
| Truck Sample 16 | Glass mirror from passenger side |
| Truck Sample 17 | Stainless steel mirror support bracket |


**(A)**

**(B)**

**Fig. 7. Photographs of the tanker truck remains at the accident site (A) and at the Caltrans storage facility (B).**

**The MacArthur Maze Fire: Materials Analysis Conclusions**

Based on the samples collected and the results of thermal exposures, the temperature of the I-580 overpass is estimated to range from 850°C [1,562°F] to approximately 1,000°C [1,832°F]. Near the truck, the maximum exposure temperature is estimated to be at least 720°C [1,328°F] and less than 930°C [1,706°F]. Results obtained from the analysis of the overpass and truck samples are consistent with modeling results, indicating the hottest gas temperatures during the fire were located above the I-880 roadway near the steel girders of the I-580 overpass. An extensive discussion of the materials analyses completed for the samples collected are provided in previous papers [4], as well as a NRC NUREG/CR series report [5].

## DETERMINING FIRE TEMPERATURES: THE NEWHALL PASS FIRE

In cooperation with CHP, staff from the SwRI® accessed the vestiges of five vehicles incinerated in the Newhall Pass tunnel fire and held in vehicle impound lots. The vehicles were visually inspected and supporting photo-documentation was gathered. Samples recovered from the vehicle remnants were used in metallurgical investigations to establish their maximum temperature exposures. The metallurgical analyses conducted on these samples were similar to those done for the MacArthur Maze materials analyses. The temperature data established bounding temperature values at selected locations in the tunnel fire.

**Description of Samples and Selection of Analytical Approach**

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. Descriptions of the samples recovered from the vehicles are provided in Table V. Figure 8 shows a schematic view of a tunnel section that includes the vehicles accessed for this study. Samples were recovered from Trucks 9, 14, 17, 18, and 27. The red circles indicate those specific vehicles and the approximate locations from which samples were acquired. The temperatures assigned to the encircled locations in

Figure 8 were obtained from the calorimetry analyses, visual inspections, and mechanical hardness measurements. Exposure temperatures were bracketed through the analysis of multiple substances obtained from adjacent locations. The temperature range provides bounds for the maximum temperature that was believed to have occurred in that location based on the materials analyses. The bounding temperature values were obtained by examining specimens that presented signs of incipient melting (only nonferrous metals) or changes in hardness values (only steel fasteners) due to the fire exposure.

**Table V. Description of Samples Collected From Incinerated Vehicles**

| Sample Identification | Description |
|---|---|
| Truck Sample 9-01 | Melted aluminum and Grade 5 bolt from trailer wheel |
| Truck Sample 9-02 | Brass Schrader valve from trailer wheel |
| Truck Sample 14-01 | Aluminum bracket holding steel cable |
| Truck Sample 14-02 | Copper wire from rear lighting of the trailer with some melted aluminum |
| Truck Sample 14-03 | Brass clamp holding a copper wire from the driver's side engine compartment |
| Truck Sample 14-04 | Melted aluminum and Grade 5 bolt from rear driver's side wheel of trailer |
| Truck Sample 14-05 | Melted aluminum flooring with imbedded steel screw |
| Truck Sample 14-06 | Melted aluminum from the grill of the tractor |
| Truck Sample 17-01 | Partially melted rear brake brass compression fitting |
| Truck Sample 18-01 | Brass clip containing copper electrical wire |
| Truck Sample 18-02 | Melted aluminum and Grade 5 bolt from wheel |
| Truck Sample 18-03 | Melted aluminum and Grade 5 bolt from wheel |
| Truck Sample 27-01 | Melted aluminum and Grade 5 bolt from wheel |
| Truck Sample 27-02 | Melted aluminum from rear of trailer |
| Truck Sample 27-03 | Brass ID tag from axle housing |

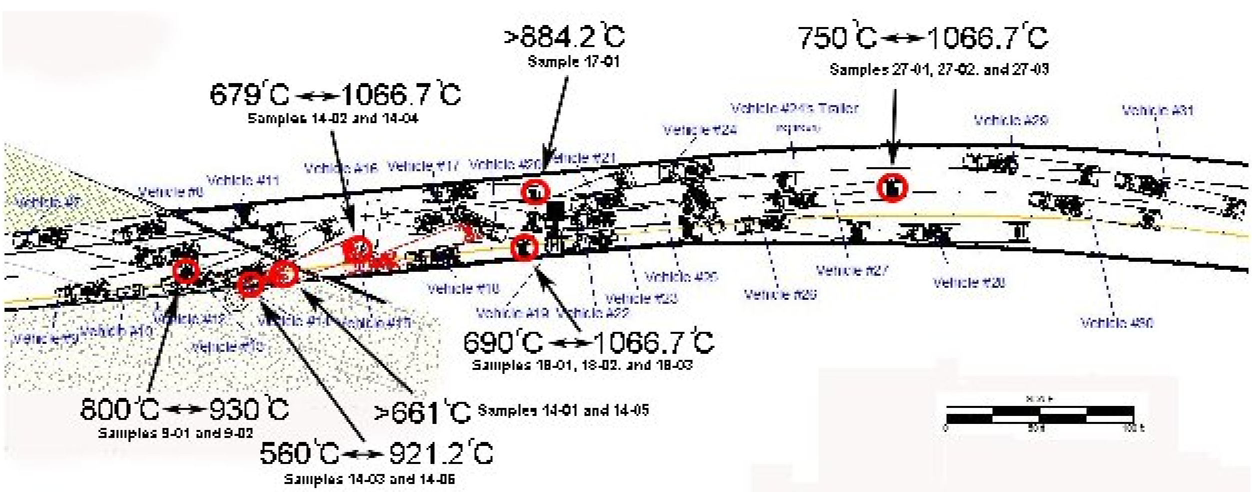


**Figure 8. Section of Tunnel With Vehicles Accessed for Sample Recovery. (Image of Vehicle Location in the Tunnel Was Provided by CHP.)**

**The Newhall Pass Fire: Materials Analysis Conclusions**

Figure 8 shows that for the location of Truck 9, the results from the sample analysis indicated that the temperature ranged somewhere between 880 and 930 °C [1,472 and 1,706 °F]. The material analysis determined the lower bound by examining the hardness of graded bolts and melted aluminum. The upper-bound temperature for this vehicle was determined by an unmelted brass Schrader valve, which is located a few feet off the ground.

The temperature range predicted by the materials analysis for Truck 14's tractor was between 560 and 920 °C [1,040 and 1,690 °F]. The lower bound determined from the material analysis was based on melted aluminum from the grill of the tractor. This would be expected to be slightly above the 1.5 m [4.9 ft] level. The upper bound temperature was determined from a brass clamp recovered from the engine compartment. This would be somewhere between 1.5 and 3.5 m [4.9 and 11.5 ft].

For the front end of Truck 14's trailer the materials analysis indicated that the temperature was greater than 660 °C [1,220 °F]. There was only a lower bound because melted aluminum was the only material recovered from that location. The temperature was determined in the materials analysis by examining a section of melted aluminum flooring.

For the backend of Truck 14's trailer the materials analysis indicated that the temperature was between 680 and 1,070 °C [1,256 and 1,958 °F]. The lower bound temperature was determined by melted aluminum wheels, which would be at the 1.5-m [4.9-ft] level. The upper bound temperature determined from the materials analysis came from examination of unmelted copper wiring.

The materials analysis indicated that the temperature range for Truck 17 was greater than 880 °C [1,616 °F]. The lower bound temperature from the materials analysis data was determined by a melted brass compression fitting ferrule.

The materials analysis of Truck 18 indicated that the temperature was between 690 and 1,060 °C [1,274 and 1,940 °F]. The lower bound of temperature for the materials analysis was determined by melted aluminum around the wheel level.

The last vehicle where the materials analyses results are reported is Truck 27. The materials analyses indicated that the temperature was at least 750 °C [1,382 °F] but did not reach 1,070 °C [1,958 °F]. The lower point on the materials analyses came from the hardness of a graded bolt. The bolt microstructure indicated it had been converted to pearlite; However, the upper-bound temperature from the materials analyses came from an unmelted plate on the axle.

**CONCLUSIONS**

For the MacArthur Maze fire, temperatures can be estimated using information collected from phase transformations in the welds and grain size of the steel girders, damage to paint on the steel girders, and the observed condition of the tanker truck materials. Samples were collected from the I-580 steel girders and the truck remains and analyzed. A limited number of thermal exposures were conducted to determine the effect of temperature on the microstructure of structural welds.

Based on the samples collected and the results of thermal exposures, the temperature of the steel girders in the I-580 overpass during the fire were estimated to range from 850°C [1,562°F] to approximately 1,000°C [1,832°F]. Near the truck, the maximum exposure temperature was estimated to be at least 720°C [1,328°F] and less than 930°C [1,706°F]. Results obtained from the analysis of the overpass and truck samples are consistent with qualitative evidence obtained from condition of the paint on the girders and the video of the fire, indicating the hottest gas temperatures during the fire were located above the I-880 roadway near the steel girders of the I-580 overpass.

For the Newhall Pass fire, temperatures were determined by the materials analyses conducted on materials collected from the various vehicles involved in the fire which indicated that the temperature in the tunnel reached levels high enough to melt aluminum (i.e., greater than 560 °C [1,040 °F]). Only Truck 17, where a melted brass ferrule was located, indicated a higher tunnel temperature (i.e., greater than 884 °C [1,623 °F]) by the melting point analysis. Additionally, hardness data was collected from graded bolts exposed in the fire. The hardness data indicated that the temperature was at least between 400 and 800 °C [750 and 1,470 °F]. Therefore, based on the results of the materials analyses, it is clear that the gas temperature in the tunnel varied with time and location, but exceeded 884 °C [1,623 °F] in at least one location.

The insights gained from the materials analyses from both the MacArthur Maze and Newhall Pass fires may be used to validate computer fire models of these two events and allow for further investigation the potential affects that fires of these magnitudes and duration could have had on an NRC certified over-the-road radioactive material transportation package, and any potential regulatory implications.

**REFERENCES**


1. 10 CFR 71. Jan. 1, 2009. *Packaging and Transportation of Radioactive Material*. Code of Federal Regulations, US Nuclear Regulatory Commission, Washington D.C.

2. Google Maps http://maps.google.com/maps?f=q&hl=en&geocode=&time=&date=&ttype=&q=oakland,+CA&ie=UTF8&ll=37.827701,-122.293367&spn=0.005762,0.007585&t=h&z=17&om=1

3. California Department of Transportation. April 29, 2007, April 30, 2007 http://www.dot.ca.gov/dist4/photography/images/070429/index.html http://www.dot.ca.gov/dist4/photography/images/070430/index2.html

4. C.S. Bajwa, D.S. Dunn, E.P. Easton. *The MacArthur Maze Fire: How Hot Was It?* Proceedings of the Waste Management Symposium, Phoenix, AZ, July 2009.

5. D.S. Dunn, R.E. Shewmaker, A.H. Chowdhury. *Analysis of Structural Materials Exposed to a Severe Fire Environment*, NUREG/CR 6987, U.S. Nuclear Regulatory Commission,Washington, DC 20555-0001, February 2009.