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Fire in the Tunnel!

A Study of Effects on a Spent Fuel Transportation Cask

Can spent fuel transportation cask designs withstand the thermal conditions experienced in the Baltimore tunnel fire?

By C. S. Bajwa

Following the July 18, 2001, derailment and fire involving a freight train inside the Howard Street tunnel in Baltimore, Md., the staff of the U.S. Nuclear Regulatory Commission's Spent Fuel Project Office (SFPO) was tasked with investigating the incident and determining if current regulations for shipping spent nuclear fuel by rail provide reasonable assurance that transportation cask designs can withstand the thermal conditions (i.e., flame temperature, fire duration, presence of flammable and other hazardous cargo) experienced in the tunnel.

Derailment Details

The accident in the Baltimore tunnel involved a CSX freight train traveling through downtown Baltimore. The Howard Street tunnel is a single-track rail tunnel, 2.7 kilometers (1.7 miles) in length, with an approximate 0.8 percent upward grade in the direction the train was traveling. The tunnel is constructed mostly of concrete and refractory brick. The tunnel has vertical walls and a circular ceiling and measures approximately 6.7 meters (22 feet) high by 8.2 m (27 ft) wide. The dimensions of the tunnel vary slightly along its length.

The CSX freight train had three locomotives and 60 cars. As the train traveled through the tunnel, 11 of the 60 cars derailed.[1] The cause of the derailment remains under investigation. A tank car transporting approximately 108 263 liters (28 600 gallons) of liquid tripropylene was ruptured in the derailment and subsequently caught fire. Liquid tripropylene carries a National Fire Protection Association hazards rating of three, for flammability. This rating signifies that tripropylene can be ignited at ambient conditions.

The freight train was also transporting tank cars full of hydrochloric acid and other hazardous materials, which were not thought to have contributed to the fire. The precise duration of the fire is unknown; however, information provided by emergency response personnel indicates that the most severe portion of the fire lasted approximately three hours.

Staff Analyses

Determination of Fire Temperatures

To better quantify the temperatures that existed within the tunnel during the event, fire modeling experts at the National Institute of Standards and Technology (NIST) were contracted to develop a model of the Howard Street tunnel fire using the Fire Dynamics Simulator (FDS) code.

As a preliminary step in the analysis, to demonstrate the capability of FDS to properly model a tunnel fire, NIST developed tunnel models to validate FDS against data taken from a series of fire experiments conducted in an abandoned West Virginia highway tunnel. The data were part of the Memorial Tunnel Fire Ventilation Test

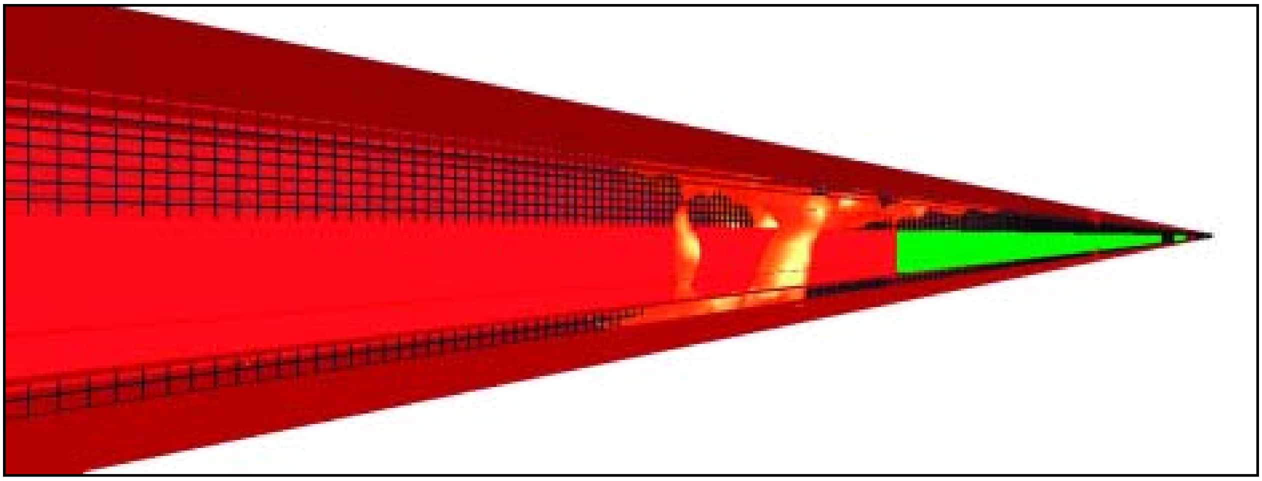

Fig. 1. Howard Street tunnel fire model. (Courtesy of NIST.)

Program performed by the Federal Highway Administration and Parsons Brinckerhoff Inc.

The Howard Street tunnel model was constructed as a three-dimensional model and modeled the entire length of the tunnel, with railcars positioned as they were found following the derailment (see Fig. 1). The FDS model predicted fire temperatures as high as 1000°C (1800°F) in the narrow flaming region of the fire. The hot gas layer above the railcars, within three railcar lengths of the fire, averaged 500°C (900°F). The tunnel surface wall temperature reached 800°C (1500°F) where the fire directly impinged on the top of the tunnel. The average tunnel ceiling temperature, within a distance of three railcars from the fire, was 400°C (750°F).[2]

Material Exposure Analysis

The physical evidence that remained following the fire was used by the SFPO staff to further confirm the temperatures reported by the NIST fire model. Staff of the Center for Nuclear Waste Regulatory Analysis (CNWRA) with expertise in fire testing, fire modeling, and materials analysis were contracted to examine the physical properties of the paint and metals from the railcars (boxcars and tank cars) removed from the tunnel after the fire. To determine the time and temperature exposure of these samples, metallurgical analyses were performed on several different materials, including sections of the boxcars exposed to the most severe portion of the fire, as well as an air brake valve from the tripropylene tank car. The CNWRA analyses demonstrated that the temperatures calculated by NIST were consistent with the conditions observed in the paint and metals analyzed.

Staff Analysis of a Spent Fuel Transportation Cask

With the assistance of thermal analysis experts at Pacific Northwest National Laboratories, SFPO developed a two-dimensional finite element analysis thermal model of a transportation cask, including the rail transport cradle (see Fig. 2). The purpose of this model was to perform a thermal assessment of the cask that captured the nonuniform temperature distributions that existed in the Howard Street tunnel fire. The staff imposed both the temperature and flow boundary conditions, calculated by NIST, on the analytic model of the spent fuel cask.

The staff examined two scenarios in this analysis. The first scenario was based on the U.S. Department of Transportation (DOT) regulations that require railcars carrying radioactive materials be separated by at least one railcar (known as a buffer car) from hazardous materials or flammable liquids. The staff's analysis assumed one railcar [20 m (65.6 ft)] separation between the center of the spent fuel cask and the fire source.[3] The staff applied temperature and flow boundary conditions onto the cask in three "zones." The upper third of the cask was conservatively exposed to the maximum temperatures and flow that existed in the upper portion of the tunnel; the middle third of the cask was con-

According to reports on the event, the liquid tripropylene fuel burned for about three hours in the actual Howard Street tunnel fire, and the tripropylene tank car held enough fuel for a burn time of only six to seven hours, based on a controlled pool fire burn with a 9-m (26-ft)-diameter pool.

In the first scenario, the upper third of the cask was conservatively exposed to the maximum temperatures and flow that existed in the upper portion of the tunnel; the middle third of the cask was conservatively exposed to the maximum temperatures and flow that existed along the side of the tunnel; and the bottom third of the cask, including the shipping cradle, was conservatively exposed to the maximum temperature and flow conditions along the lower elevations of the tunnel.

servatively exposed to the maximum temperatures and flow that existed along the side of the tunnel; and the bottom third of the cask, including the shipping cradle, was conservatively exposed to the maximum temperature and flow conditions along the lower elevations of the tunnel. The cask model accounts for the effects of radiation from the tunnel walls and the effects of the mounting cradle that secures the transportation cask to a specially designed railcar.

The second scenario placed the center of the cask 5 m (16.4 ft) from the fire source. This scenario is considered unrealistic for this particular accident, since it is unlikely that a spent fuel transportation cask, had one been involved in the Howard Street tunnel derailment and fire, would have been adjacent to the fuel source.

For both scenarios, the fire was assumed to burn at the maximum temperatures calculated for 150 hours. According to reports on the event, the liquid tripropylene fuel burned for about three hours in the actual Howard Street tunnel fire, and the tripropylene tank car held enough fuel for a burn time of only six to seven hours, based on a controlled pool fire burn with a 9-m (26-ft)-diameter pool.

Transportation Cask Analytic Model Results

For the 20-m (65.62-ft) scenario, the analysis indicated that the short-term temperature limit of the Zircalloy fuel cladding, 570°C (1058°F),[4] would have been exceeded 116 hours into the fire exposure. For the 5-m (16.4-ft) scenario, the fuel cladding temperature limit would have been exceeded at 37 hours into the fire exposure.

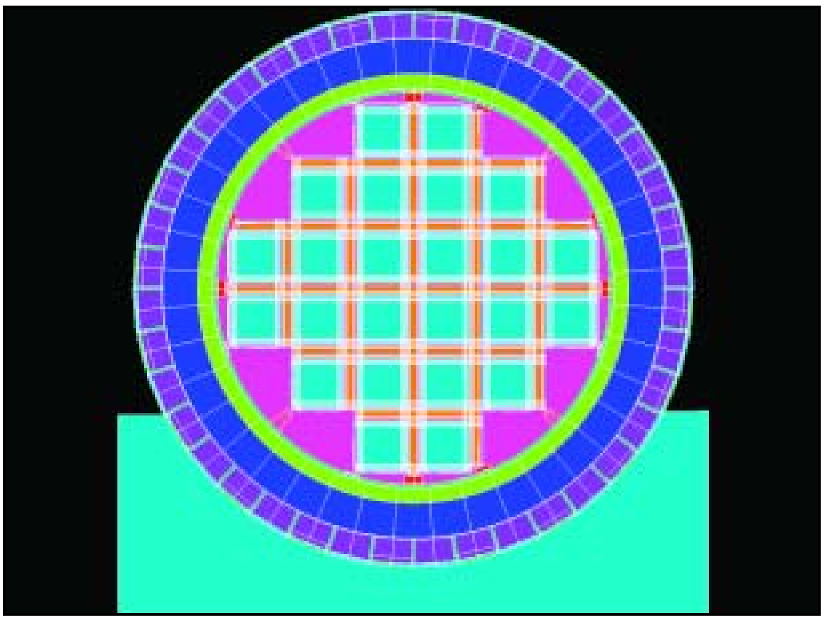

Fig. 2. Finite element model of spent fuel transportation cask.

The short-term temperature limit is a conservative regulatory tool used to ensure no fuel rod cladding breach. It is not a temperature limit that implies gross rupture of fuel cladding. Additional calculations were performed to determine stresses that resulted from the fire in the welded multipurpose canister (MPC) that provides the primary boundary to release of radioactive materials.[5] The stress calculations indicated that the MPC would not fail during the fire, and thus there would be no radioactive release for the event.

The staff also examined the risk of radioactive doses to first responders after a severe fire accident. Since the cask's polymeric neutron shield would be damaged under severe fire conditions, the magnitude of the neutron field would increase in the vicinity of the cask. This condition is accounted for in the safety analysis report of the transportation cask in question.[6] For the hypothetical accident condition fire in 10 CFR 71.73, the neutron shield for this cask was assumed to be consumed. The licensing analyses for this cask demonstrated that without the neutron shield, the postaccident dose rates would be within the limits prescribed in 10 CFR 71.51. Therefore, the complete loss of the neutron shield does not pose a risk to public health outside those allowed by NRC regulations.[7]

No Public Health or Safety Concerns Identified

The NRC's assessment of the hypothetical event of a spent nuclear fuel transportation cask being present during the Howard Street tunnel fire identified no public health or safety concerns. The staff's analyses indicated no failure of the structural components of the transport cask or failure of the canister containing the spent fuel inside the transportation cask. Consequently, the staff concluded that there would be no release of radioactive materials from this postulated event.

The staff believes that the robust nature of spent fuel transportation casks in general, and the cask design reviewed in this analysis, in particular, provide reasonable assurance of adequate protection to the public. The fact that current DOT regulations require a buffer car be used to separate a spent fuel cask from any railcar carrying hazardous materials provides an added measure of safety to transporting spent nuclear fuel by rail.

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