USDA Forest Service

Twisp River Fire
Personal Protective Equipment (PPE)
Analysis and Fire Equipment Report

To accompany Twisp River Fire Fatalities and Entrapments Learning Review Narrative
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Twisp River Fire Personal Protective Equipment (PPE) Analysis

The Twisp River Fire entrapped 16 firefighters, killing three firefighters in USDA Forest Service Engine 642; severely burning another firefighter who escaped from Engine 642; entrapping three firefighters who deployed fire shelters; and entrapping three additional engines with personnel. The personal protective equipment (PPE) and gear that was recovered was visually inspected for indications of heat and flame exposure.

**Forest Service Engine 642 PPE**

All PPE from the three firefighters who perished in Engine 642 was consumed by the vehicle fire. No PPE remained to be inspected.

When Engine 642 drove off Woods Canyon Road, the vegetation was most likely burning. The firefighter who escaped from Engine 642 suffered significant burns but survived. He was exposed to the full temperatures of an active fire, probably 1600 to 1800°F. His helmet and flame-resistant (FR) shirt were found on Woods Canyon Road (see locations in figure 1). In addition to those items, his boots and FR pants were collected and inspected.

![Figure 1. Twisp River fire entrapment area.](image-url)
Flame-resistant (FR) Clothing

The injured engine crewmember’s FR clothing was exposed to heat that caused the shirt and pants to become brittle and charred over much of the fabric. Charring begins at a temperature of 825°F. The firefighter removed his shirt (Forest Service specification 5100-91), which was found on Woods Canyon Road approximately 80 yards from Engine 642. The areas of the shirt that were most significantly affected were the front, arms, sides, and the sides along the back. All the buttons that were fastened are missing. The back of the shirt has a large area that was mostly unaffected. The pants (Forest Service specification 5100-92) were significantly affected on both the front and back. The firefighter was exposed to temperatures of 1600 to 1800°F, likely for several seconds. The clothing appears to be charred similar to clothing exposed in a four-second flame engulfment test performed by the Protective Clothing and Equipment Research Facility in Edmonton, Alberta.

Figure 2. Engine crewmember FR shirt front.

Figure 3. Engine crewmember FR shirt back.

FR clothing is designed to prevent ignition of the clothing itself. This lessens a burn injury in a situation where the designed performance standards are exceeded, as they were in this incident. The firefighter also wore a short sleeve cotton blend shirt under the FR shirt, which likely lessened the burn injury to his upper body.
The firefighter’s helmet was found on Woods Canyon Road about 150 yards from Engine 642. It is a Bullard Wildfire Series Fire Helmet model FH911C. The brim is deformed (the thermoplastic material begins to melt at 325°F); the left side reflectors are shrunk and mostly melted; the right side reflectors have curled edges; the chinstrap shows dye sublimation (occurs at 425°F) and has melted loop closures; the suspension has a small amount of melt on the webbing; one suspension key is detached; the ratchet adjuster is inoperable; the lower edge of the brow pad is slightly melted; and the anti-glare strip has melt on the edges. After the helmet was dropped on the road, a retardant drop was made that covered the helmet.
Boots

The firefighter’s boots are Danner brand with a Vibram sole. Many of the threads holding the leather sections together either burned or melted, and one panel on the inside ankle of both boots was burned away. The material at the top of the ankle was partially melted.

**FD6 Engine 4, COOP Engine 1, and Contractor Engine 1**

The PPE from the firefighters on Okanogan County Fire District 6 Engine 4, Cooperator Engine 1, and Contractor Engine 1 showed no visual indications of exposure to heat.
After the heavy equipment boss (HEQB), heavy equipment boss trainee (HEQB (t)), and dozer operator (DZOP) left the burning garage of house 3, they passed the burning house and went out the driveway toward Woods Canyon Road. The majority of the surrounding vegetation had already burned. They paused at the wye because the air was less smoky, and they felt the danger from fire behavior had passed. They deployed fire shelters on the road because there was uncomfortable residual heat coming from their surroundings. They had two fire shelters at the deployment site; the DZOP had left his on the dozer, so the HEQB gave his fire shelter to the DZOP. The HEQB laid down, and the other two firefighters laid across the HEQB with their feet toward the heat, shielding the HEQB with the fire shelters (see diagram in figure 9). No difficulties were encountered when removing the fire shelters from their packs or tearing open the PVC bag. Judging from interviews, equipment inspections, and site visits, no fire events that would cause additional burn injuries occurred once they were in the fire shelters; therefore, this fire shelter deployment is categorized as precautionary.
Since the HEQB (t) and DZOP were kneeling over the HEQB, gaps between the fire shelters and ground were present. The DZOP mentioned feeling some heat on his leg through one of these gaps where his pants were tight against his skin. The fire shelters made their time at the wye more comfortable and could have protected them from a change in fire conditions if one occurred.

The firefighters each received first- and second-degree burns on their ears, and the HEQB dropped a glove and received second-degree burns on his bare hand. The radiant heat from being inside the garage and escaping past the burning house most likely caused the burns.

### Dozer Group FR Clothing and Personal Protective Equipment

**Fire shelters and PVC bags**

The fire shelters showed no indications of exposure to high temperatures. One regular-size fire shelter (manufactured 1/2005) and one large-size fire shelter (manufactured 4/2006) were deployed. The regular-size fire shelter has a small amount (one percent of the surface area) of end cap abrasion, most likely from standing and kneeling on the fire shelter during the deployment. Both fire shelters have speckles of retardant on them. One of the PVC bags had a one-inch diameter area of melt deformation, but otherwise both showed no indications of exposure to high temperatures.

![Figure 10. Fire shelter that was deployed during the Twisp River Fire entrapment.](image1)

![Figure 11. Fire shelter PVC bag and pull strip.](image2)
Flame-resistant (FR) Clothing

The FR clothing has several dye sublimation marks and char (about 1/8-to ½-inch diameter), most likely from contact with hot embers. The HEQB (t)'s shirt had a burn through the fabric (about ½-inch long and 1/8-inch wide). Exposed hook and loop closures showed a small amount of melting. Ember strikes will often show dye sublimation with charring in the center. Dye sublimation occurs when the fabric reaches a temperature of 425°F, and charring occurs at 825°F.

Figure 12. FR shirt (Forest Service specification 5100-91) from dozer group.

Figure 13. FR pants (Forest Service specification 5100-92) from dozer group.
Gloves
The HEQB dropped one leather glove along the driveway when moving toward Woods Canyon Road. This glove was found to be shrunk around the wrist and upper hand, indicative of temperatures around 350°F.

Helmets
Helmets showed no signs of exposure to high temperatures except that one helmet has a curled anti-glare strip.

Fire Shelter Deployment Reminders and Discussion Points
Packs can hinder a fire shelter deployment and can contain fusees and saw gas. Remove packs and toss them away from the deployment site before getting into a fire shelter. Review the National Wildfire Coordinating Group publication “The New Generation Fire Shelter”² (PMS 411) for reminders of other items that should be thrown away from a fire shelter.

Keeping gloves in an easily accessible location and wearing them during the entrapment likely prevented burn injury to the DZOP’s hands. Firefighters working jobs that require hand dexterity should keep gloves in an easily accessible location, such as a pants pocket or attached to a carabiner on their waist when not wearing them.

The DZOP from this incident secures his gear to the dozer so nothing will fall off during operation. He believed they would be protected enough by the garage that he would not need his fire shelter, so it was left on the dozer. Conditions quickly changed, and it was too hot to climb back onto the dozer to unstrap the fire shelter. He now plans to wear the fire shelter with a chest harness. Dozer and other heavy equipment operators should consider using a chest harness, which is available through the Defense Logistics Agency (DLA) as NSN 8465-01-463-4648.

Figure 15. Example of a heavy equipment operator wearing a fire shelter chest harness.
Twisp River Fire Equipment Report

Key Points

- Vegetation was either burning or had just burned when the fire engine left the road.
- The surviving firefighter was in the vehicle for a short period of time when it was exposed to extreme heat. The door mechanism was still functioning when he escaped.
- Most likely a rapid increase in temperature occurred when the cab integrity was compromised.
- The majority of the damage was sustained from the vehicle fire.

General Discussion – Vehicle Fires

One USDA Forest Service specification and one consensus standard govern the construction of a wildland fire apparatus used by the Forest Service. The consensus standard is the National Fire Protection Association (NFPA) Standard 1906, Standard for Wildland Fire Apparatus. Type 6 engines are constructed from a commercial chassis. The chassis portion of the Forest Service specification 643U outlines minimum requirements and standard options for the commercial chassis. The apparatus body portion of the specification outlines the construction and installation of the body. Any deviation from these specifications requires review and approval. The body of the fire engine is constructed and installed on the commercial chassis by the final-stage manufacturer.

Effects of Fire on a Vehicle

When exposed to sustained heat, various vehicle components will support flaming ignition. In previous laboratory experiments and field tests, plastic outside mirror structures, vehicle paint, and tires were observed to ignite first. Literature and field testing indicate that tires ignite when exposed to temperatures above 600°F (315°C). This ignition supports further combustion.

The cab contains materials constructed from polypropylene (most of the interior), PVC (seat cushions), and Acrylonitrile Butadiene Styrene (ABS) (door panels and handles). Scientific literature estimates that 200 lbs. of plastics are used in passenger vehicles.3 These materials will ignite at temperatures as low as 500°F (260°C). These materials will also sustain combustion.

Federal Motor Vehicle Safety Standard (FMVSS) No. 302 outlines the test procedures and requirements for the spread of flames from burning plastics in a vehicle. The FMVSS sets the rate of spread in materials to be 4 inches/minute maximum. This rate, however, is exceeded when the integrity of the cab is compromised and the interior is exposed to direct flame.4 The likelihood of a rapid increase in temperature and near simultaneous ignition in the cab is also increased when the cab is compromised. The integrity of the cab can be compromised by the melting or breaking of the glass or through openings in the floor.

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Vehicle windshields in the United States are made using laminated glass. In laminated glass, a thin plastic sheet (polyvinyl butyral-PVB) is sandwiched between two sheets of glass. This plastic sheet prevents the glass from shattering into small pieces. In laboratory experiments, laminated glass starts to melt at a temperature of 716°F (380°C).

Side windows are, in most cases, tempered glass. In laboratory tests, tempered glass allows twice as much radiant heat than any other glass. Tempered glass will start to fail at temperatures above 200°F (100°C).

Door handles, bushings, and linkages in the doors in most vehicles are made of ABS. ABS will start melting at 446°F (230°C). The melting or burning of the door handles and door mechanism makes egress difficult.

**Type 6 Engine (Model 643U)**

**Forest Service Type 6 Engine Configuration**

The Forest Service Type 6 fire engine (Engine 642) met the performance requirements defined by the Forest Service specifications (cab and chassis). The Type 6 fire engine also met the requirements of NFPA 1906 except as specifically required in the Forest Service specifications. A review of the preventative maintenance records and service records did not show any issues that would affect the fire engine’s performance.

The engine chassis is a 2012 Ford F550XL Crew Cab. The Ford F550XL is powered by a 6.7 liter diesel engine. Four-wheel drive is standard for a Type 6 engine. Additional requirements included two (2) batteries, power windows, power door locks, and cruise control. The Gross Vehicle Weight Rating

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5 Glass assembly study – SDTDC, U of Alberta.
(GVWR) is 19,500 lbs.: front axle capacity of 7,000 lbs., rear axle capacity of 13,500 lbs. The standard commercial chassis is equipped with an auto shutdown feature to reduce the time the engine idles. This feature was disabled as required in the specification.

Staffing for a Forest Service Type 6 engine varies from two to five firefighters. The engine has a capacity for five people. The seat belts were upgraded to meet NFPA 1906 standards. The driver, front passenger, and rear outboard seat position all had red three-point seat belts.

**Visual Inspection – Forest Service Engine 642**

It is most likely that when Engine 642 left the road, the vegetation in the cut bank had either just burned or was burning. The brush in the path of the vehicle showed scrape marks that remained unburned.  

As the vehicle traveled forward traversing the side slope, it slid laterally and continued to move forward until coming to rest.

Examination of the surviving engine crew member’s fire shirt and fire pants indicated exposure to a high amount of heat inside the vehicle for a short period of time. The period of time can be
approximated because the firefighter was able to exit the vehicle. Door mechanisms were still functioning.

![Figure 4: Engine 642 cab deformation.](image)

The heat from the vegetation fire ignited the vehicle. The combustible materials in or on the vehicle (i.e., tires, seat cushions, etc.) sustained the fire and were completely consumed. The majority of the damage on the fire engine was sustained during the vehicle fire.

![Figure 5: Aluminum tread plate, rear passenger side of cab, Engine 642.](image)
Only the metal structure of the chassis and the metal slip-on body remained after the fire. All plastic, glass, and rubber material were consumed. Deformation of the cab roof and steel leaf springs indicate temperatures over 1800°F.

The rear passenger side of the vehicle sustained the least damage compared to the rest of the vehicle; this was the downhill side. A small section of aluminum tread plate remained unburned. The laminated windshield glass was melted, and the tempered window glass shattered. No conclusions can be made as to when the cab was compromised. Further inspection of the doors indicates that the front passenger, rear passenger, and rear driver side windows were rolled up. It is most likely that the driver window was also up.

![Figure 6: Engine 642 front passenger seatbelt.](image)

The male end of the front passenger seatbelt buckle was found by the front passenger door, indicating that the seatbelt was not fastened. However, it cannot be determined when the seat belt was unbuckled.

The Ford F550 chassis was equipped with secondary restraint system (airbags); however, it cannot be determined whether these deployed and whether any deployment was due to impact or the heat.
Other Twisp River Fire Apparatus

Contractor Engine Type 6
This vehicle showed little signs of damage due to heat. No melting of exterior plastic parts occurred, such as turn indicators or exterior rear mirrors. The only sign of heat exposure is a small burn on the air filter. However, it cannot be determined when this occurred.

Rural Fire Department – Type 3 Fire Apparatus
The RFD Type 3 engine showed very little evidence of exposure to heat. The vinyl covers on the hose bed were completely melted. Vinyl melts at a temperature range of 167°F to 221°F.

Dozer
The dozer is a Caterpillar D4H with an open cab. The dozer sustained major damage. Most of the interior plastics were burned. Unlike a fire engine, the dozer had very little plastic or rubber components to sustain an equipment fire. A majority of the external burning was from the
vegetation fire. Internal components were first ignited and continued burning until all non-ferrous materials were consumed.

The right side and front of the dozer showed signs of more intense exposure to heat. This was the side exposed to the flame front.

The left side showed little evidence of high-heat exposure. It is most likely that the deposition of soot was from the interior fire. The paint was still intact. The engine compartment did not show signs of soot.
Figure 11: Dozer’s left-side engine compartment.