Fire in the Heinenoordtunnel, Lessons learned.

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ABSTRACT:
On May 21th 2014 a truck blew out a tyre and crashed into the wall of the Heinenoordtunnel nearby Barendrecht, The Netherlands. On impact the truck instantly caught fire and slided over more than 75 meters to the lowest point of the tunnel. The Rotterdam-Rijnmond Fire Department, the Ministry of Infrastructure and Environment (owner of the tunnel) and Efectis Netherlands BV collected information about this recent fire, focussed on fire fighting operations, communication during the incident, fire development in the tunnel and the performance of tunnel safety measures like escape doors, ventilation system and tunnel lining.

The Fire Departments Investigation Team collected information in the tunnel, about the origin and specific development of the fire, the performance of the tunnel safety measures, like escape doors and fire fighting equipment.
The Ministry collected data from the traffic cameras in the tunnel. These cameras recorded the accident, large parts of the evacuation and the fire fighting efforts.
The Fire Department, the Ministry and the Police collected information about the tunnel safety measures. They also collected data about the incident management by debriefing the Fire- and Police officers and traffic managers involved in rescue, fire fighting, communications and traffic management. This was done in a round table discussion with all first responders involved (Leertafel).
Efectis NL collected data on the development of the fire, the fire load of the truck and the structural damage to the tunnel and estimated the Heat Release Rate during the fire.

The research resulted in two reports [1, 2], one about the incident management and communication and one about the fire development.

KEYWORDS: tunnel fire, spalling, fire development, evacuation, fire fighting, human behaviour

INTRODUCTION

In the Netherlands tunnels in highways are mostly used to cross the rivers and therefore tunnels are immersed. These immersed tunnels are build on a remote location, the segments are sealed and transported floating over the river to the tunnel construction site, placed in a trench on the river bottom and covered with dirt. New tunnels are designed to withstand a fire related to the RWS - fire curve for 2 hours. Existing tunnels are retrofitted with a tunnel lining to withstand this fire curve. Because a lot of the tunnels are positioned in the highway network used for transport to and from the ports of Rotterdam, Amsterdam and Schiphol, the tunnels should withstand such a large fire mainly to prevent a long closure of this tunnels and to prevent the blockage of (one of) the most important transport network(s) in The Netherlands.

On May 21th 2014 a truck crashed into a wall of the Heinenoord tunnel near Barendrecht, The Netherlands and caught fire. The Heinenoord tunnel was closed for traffic for almost 19 hours. This caused a 100 km long traffic jam in the area of Rotterdam.

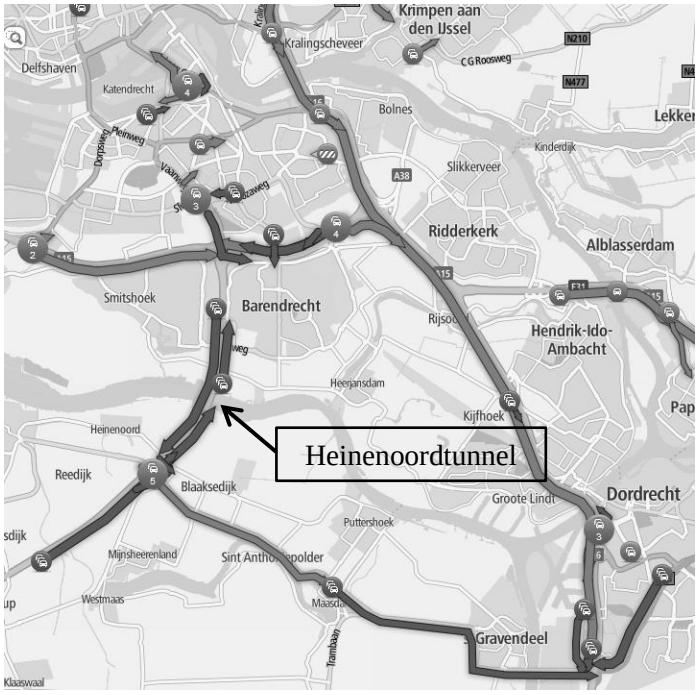

Figure 1 100 km of traffic jam around Rotterdam (source: www.livetraffic.nl).

The truck driver didn't survive the accident and two other people who were involved in the accident managed to escape their burning vehicle but got severely injured.
The tunnel (owned bij Rijkswaterstaat, Ministry of Infrastructure and Environment) is monitored by an operation centre for traffic management near Rotterdam.
The Netherlands is devided into 25 safety regions, each with it's own combined dispatch for Police, Fire Department and Ambulance. The Heinenoordtunnel is placed on the border between two of these Safety regions (Rotterdam-Rijnmond and Zuid-Holland Zuid). Fire Departments and Police units from both sides of the tunnel responded to the fire.

THE HEINENOORD TUNNEL

The Heinenoordtunnel was opened in 1969 as part of the highway A29 near Barendrecht.The tunnel is part of the European Trans European Tunnel network (TEN-netwerk). It fulfills al the criteria from EU directive EU 2004/54/EG [13] and the more strict safety criteria from the Dutch legalisation (Wet Aanvullende Regels Veiligheid Wegenverkeerswet, WARVW) [14].The tunnel is an immersed tunnel under the river "Oude Maas" that was built in sections of 8,8 meter high, 30,7 meter wide and 115 meter long and gives room to 2x 3 traffic lanes. The tunnel has a length of 614 meters and is used by ±85.000 motor vehicles/day [3].

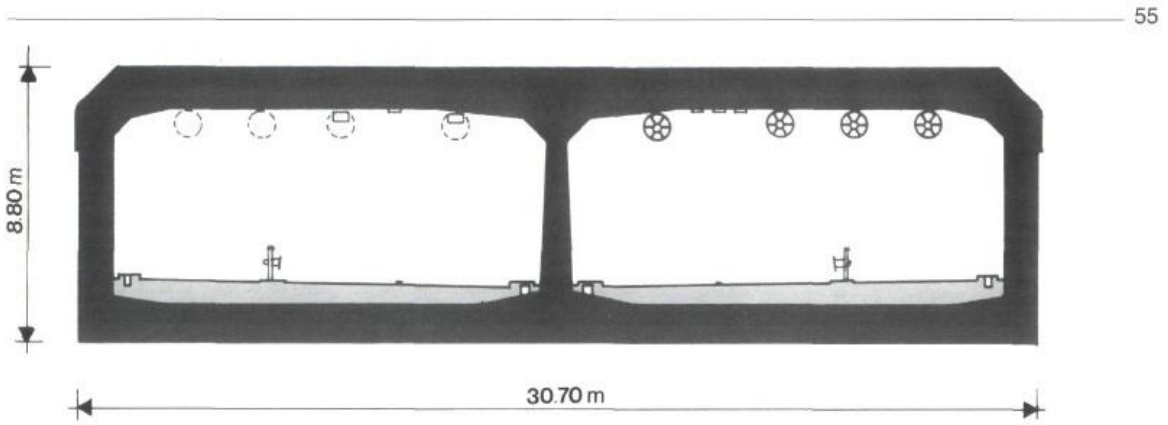

Figure 2 Cross section of the tunnel as it was designed for highway traffic(4 lanes) and low speed

traffic (2 lanes).

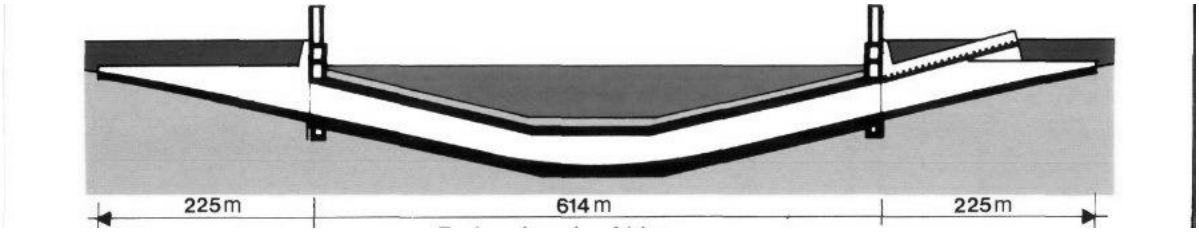

Figure 3 Longitudinal cross section of the tunnel.

The original tunnel design for a combination of high speed and low speed traffic (Figure 2) was altered to a tunnel only for high speed traffic. Along the wall in the middle of the tunnel, concrete barriers are placed on both sides to create an 1,25 meter wide evacuation path. Every 100-125 meters an escape door is positioned in the middle wall.
The tunnel is equipped with a longitudinal ventilation system, a public address (PA) system, emergency phones and fire hoses. The lights on the tunnel roof are made of LED's. Illuminated signs point to the nearest escape door and the fire fighting equipment. The tunnel ceiling and upper part of the walls are protected with a 27,5 mm thick PROMATECT-H lining.

THE INCIDENT

At 13:30:51 on May 21th the Fire department was alarmed for a fire in the tunnel. According to an eye witness on Youtube (and the camera footage), a tyre of the truck (a Mercedes-Benz Actros 1841 LS) involved in the accident blew up. The truck drove into the concrete barrier and the tunnel wall on the left side. After hitting the wall the truck turned over and immediately caught fire. In the crash the truck hit another car (Ford Fiësta, 2013). The truck slided while burning over approximately 100 meters through the tunnel and stopped, blocking 2,5 lanes of the tunnel. The car that was hit by the truck turned upside down right behind the truck. The driver and passenger of the car got out on their own with severe (burn) injuries. The truck driver died in the accident.

Figure 4 Crash and start of the fire.

The truck stopped near the middle of the tunnel. Traffic in front of the truck was able to exit the tunnel. The traffic behind the truck came to a halt. Through the PA system people were instructed to leave their car and exit the tunnel. An eye witness (a public bus driver) who entered the tunnel right behind the truck describes a calm evacuation [4]. According to the bus driver people were following instructions.
The camera images show people backing up and turning their cars (Figure 5). One person parked his car across the third lane and leaves it there.
According to the camera images from the tunnel, the fire lasted for about 31 minutes. The cabin of the truck, the container floor, the truck tyres, the (diesel) fuel and the front of the car were consumed by the fire. The cargo load of the truck in the 40'container consisted of drums filled with salt, stacked on wooden pallets. Most of the wooden pallets and the drums were consumed by the fire. The salt was still in the container.

Figure 5 Evacuation.


Figure 6 Picture taken from the tunnel entrance. The cross section of the tunnel just behind the truck is engulfed in flames (source: Twitter @RichardMaasdijk).

DATA COLLECTION

To estimate the heat release rate of the fire, data about the fire load, the duration of the fire and the fire fighting operations were collected. Data collection started with an inspection of the tunnel directly after the fire was extinguished. A team of fire investigators from Efectis and the Rotterdam-Rijnmond Fire department made pictures of the fire damage and the truck involved in the accident. The speed of the fire growth and the duration of the fire were determined from the camera footage.

The data about the fire fighting operation was collected by a method called "Leertafel". This method is used to evaluate the operations of Fire Department, Police and other agencies involved during an incident by letting the first responders tell their story about what they saw, did and experienced. The goal of this method is to learn from an incident and to improve procedures and gain knowledge about specific incidents. This method is not used for juridical reasons ore to blame persons for possible mistakes. It requires an open mind from the persons involved in the incident respons to tell their story in a save environment. This method is relatively new in the Netherlands and have recently been used at other incidents.

Fire load
The fire load was estimated based on information of several sources [5, 6, 7, 8]. In table 1 an estimation of the fire load involved in the fire is given.

Table 1 Estimation of the fire load.

Object	Mass (kg)	Total Energy (MJ)
Plastics on the truck	572	17.732
Tyres on the truck	420	11.760
Diesel fuel	360 (worst case)	15.120
Trailer floor	590	9.912
Trailer tyres	420	11.760
Trailer load (pallets)	480	8.380
Trailer load (cardboard or cellulose fibre)	1.080	17.604
½ Car (Ford Fiësta)	n/a	2.625
Total		94.893

Tunnel protection and damage to the tunnel
The tunnel roof and the upper parts of the walls are protected with a 27,5 mm thick PROMATECT-H lining. The lining is mounted in 1990. The damage patterns on the wall next to the truck cabin indicate the influence of longitudinal ventilation. Figure 7 gives an impression of the damage pattern on the tunnel wall. The damage extends in the direction of the airflow. The lines in Figure 7 give an indication of the shape of the damage.
In the direct vicinity of the truck cabin the concrete wall showed damage due to spalling. A maximum spalling depth of 2,5 cm was measured. The concrete showed a buff discolouration, which indicates temperatures reached more than 1.000 °C [9]. The discolouration of the concrete was only visible around the cabin and can be explained by direct flame impingement.

Figure 7 Damage to the tunnel wall and ceiling.

Under the tunnel ceiling a lighting system was installed consisting of LED lights. Most part of this lighting system was still working after the fire. Some parts were melted or soothed. In Figure 8 the damage to the lighting system is visible in an overview of the accident area in the tunnel.

Figure 8 The damaged lighting system still functions.

Fire Fighting operations

The accident in the tunnel was called in at the dispatches of Rotterdam-Rijnmond and Zuid-Holland Zuid. A person in the tunnel called the the emergency number 112 and told the Fire Department at Rotterdam-Rijnmond Dispatch that a bus was on fire in the tunnel. At the same time Rijkswaterstaat Traffic Control reported the accident (collision with a fire) in the tunnel to the Police Department at Rotterdam-Rijnmond dispatch. The Police told the traffic controller to report the fire at the dispatch in Dordrecht.

The traffic controller immediately, after seeing the accident, pushed the emergency button to put the tunnel in "accident mode". Pushing this button makes the fire extinguishing pumps and ventilation start, the light level goes to 100% and the P.A. system starts giving the evacuation instructions.

The first arriving unit was a Police unit from the south side of the tunnel. At that moment the tunnel was closed for traffic and the P.A. system urged people to evacuate the tunnel. The first Fire truck (from Zuid-Holland Zuid) also came from the south side. This fire truck was responding to a 112 call for a car or bus fire just outside the tunnel. When they arrived they were confronted with a tunnel fire with a lot of smoke coming out of the tunnel exit (Figure 9). This unit decided to drive the fire truck over the tunnel complex to get to the other lane and went into the tunnel through the safe side of the tunnel. The unit tried to investigate the situation in the tunnel tube where the fire was by entering through the escape doors in the tunnel wall.

Figure 9 First arriving Fire truck.

The Traffic control centre has not communicated the right (escape)door number, related to the position of the burning truck, to the Fire Brigade. Some of the escape doors were jammed which made the search for the fire location and the position of potential victims on the downstream side of the fire difficult.

The second Fire truck (from Rotterdam-Rijnmond) arrived at the north side of the tunnel. They had to wait until the correct barriers at the side of the road were opened before they could enter the tunnel trace. This took some time and because of that the third unit (from the Rotterdam fire department) arriving at the fire from the north side, was the first unit who could actually see the fire. This unit was not in (radio)contact with the unit from Zuid-Holland Zuid. Because they were going for an incident with a potential for a lot of victims (a bus fire in a tunnel), they went (not conform procedure) into the tunnel tube with the burning truck and discovered the two victims from the car involved in the crash. The victims were able to escape their car by them self. The fire was first attacked using a hoseline from a tunnel emergency unit. Because of a malfunction in this unit a foam tender was called to fight the fire in the tunnel.

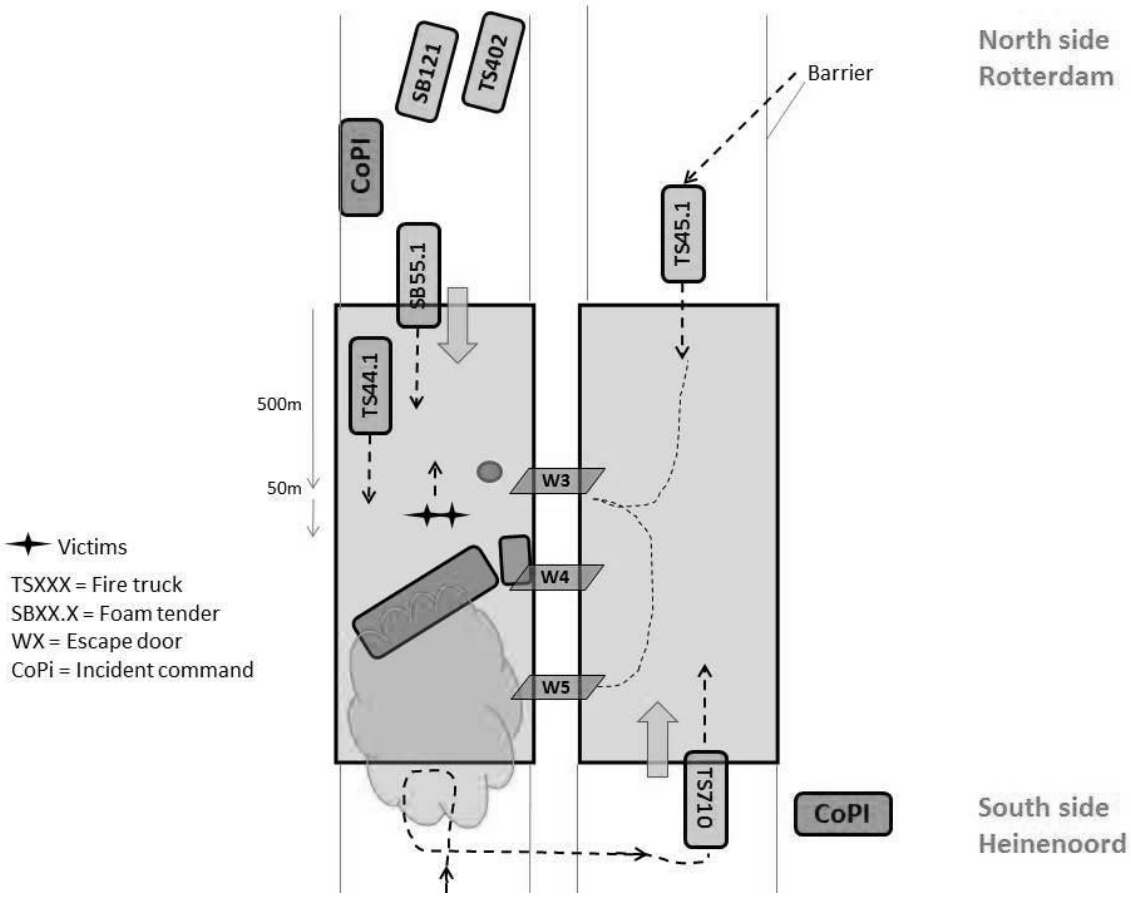

Figure 10 Overview of fire fighting operations.

Figure 11 Fire Fighting operations.

ANALYSES

Heat release rate

Based on the duration of the fire and the estimated amount of materials consumed by the fire, it is possible to calculate the heat release rate during the fire.
The data collection shows that a total amount of energy of 94.893 MJ was present in the tunnel. Most part of this "fuel" was consumed by the fire. Parts of the pallets in the container were still visible. The amount of fuel burned is estimated to be 90%. The heat release rate is calculated based on a total amount of energy of 85.404 MJ.
The camera footage shows that the fire grew quickly (within one minute) directly after the crash. This rapid fire development can only be explained by a ruptured fuel tank. The hypothesis of a ruptured fuel tank is confirmed by the fact that just after the crash a reflecting surface (pool of diesel fuel) is visible between the truck and the car behind the truck.
The fire department was alarmed around 13:30 h and the first attempt to extinguish the fire was made around 13:46 h. It is estimated that between the crash and the alarm a couple of minutes passed by. An

exact timeline could not be defined, because there was a difference in time registration on the involved systems from the Traffic control Centre and the Police and Fire Departments of Rotterdam-Rijnmond and Zuid-Holland Zuid.
The analysis of camera footage leads to a fire curve that grows to a maximum in 1 minute and maintains about the same rate of heat release (HRR) during 18 minutes. The fire lasted for a total of 31 minutes.
Within the remaining 12 minutes the fire decayed and was extinguished by the fire department.
The peak output of the fire is estimated to be between 50 and 65 MW. In Figure 9 the estimated fire curve is given. The fire curve given in figure 9 is a simplified curve because there is only limited data on the development of the fire.

The Dutch highway tunnels are designed to withstand a fire according to the RWS [10] curve for 2 hours. The heat output and the duration of the fire in the Heinenoordtunnel was below this curve. Tests performed under the UPTUN [11] and Eureka [12] projects showed the HRR for a heavy goods vehicle to be between 70 and 200 MW. Due to the fact that the truck load did not burn in this fire the HRR was much lower than could be expected.

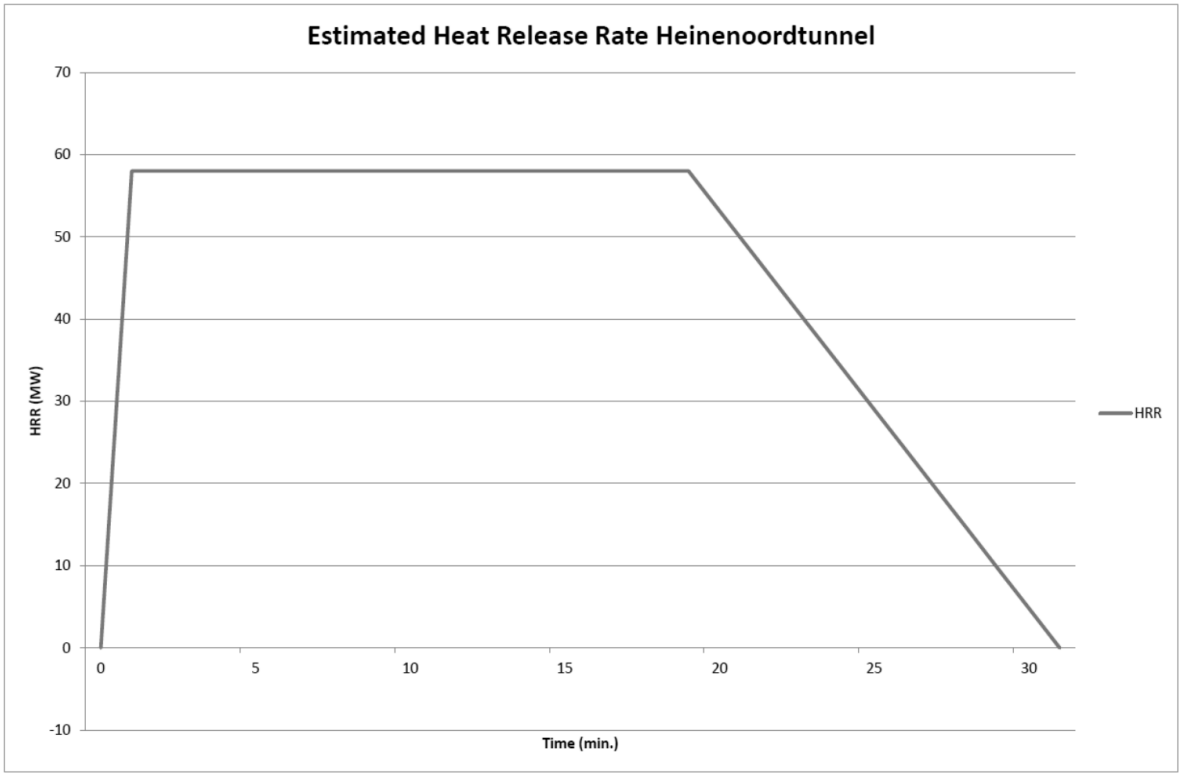

Figure 12 Estimated fire curve.

Performance of the tunnel lining
From within the tunnel the PROMATECT-H lining showed no visible damage. After editing the photo used in Figure 7 it became visible that some parts of the tunnel lining were cracked. It is not possible to determine whether these cracks are a result of the fire or were present in the lining before the fire occurred.

Performance of the longitudinal ventilation system
On the video footage no back layering of smoke is visible. The smoke stain on the tunnel ceiling and walls indicate that the ventilation system in the incident tube was functioning properly.
It is safe to state that the ventilation system in the incident tube was functioning the way it should during the fire.
Almost no heat damage occurred beyond 40m from the fire (downstream). 60 m beyond the burning

truck and further away there was more damage and pollution to the installations in the tunnel. Although all systems remained functional, the damage and smoke pollution in and on the installation makes a replacement in due time over a total length of 200 m necessary.
The tunnel cross section behind the burning truck was filled with smoke which indicates a laminar flow through the tunnel cross section.

Evacuation
The evacuation is visible on the video footage. Traffic stopped directly behind the truck and the car involved in the crash. At first some cars backed up and one van turned around. One car was parked across the left lane. The professional drivers (two public bus drivers) initiated an evacuation and through the PA system people were told to leave their car and exit the tunnel. One of the truck drivers instructed other drivers to leave the tunnel. The evacuation went calm and in order.
None of the people in the tunnel used the escape doors located in the tunnel wall. All people walked towards the tunnel entrance. The escape route these people took had a length of about 200 - 250 meters. Between the accident and the first car that stopped were two escapedoors. All people evacuating from the busses and the cars directly behind the accident passed at least one escape door on their way towards the tunnel entrance.
The two victims in the car managed to escape the burning vehicle. When the fire department arrived they walked towards the fire truck and were treated for burn injuries by the first arriving fire fighters.

Fire Fighting operations
In the Netherlands it's not usual to get into a tunneltube with a fire truck while there is an actual fire going on in that tunneltube. According to the tunnel procedure the first fire truck approaches a fire in a tunnel with separated tunnel tubes along with the direction of travel through the opposite and secure tunnel tube. Through the emergency doors a search is performed to determine from which tunnel the fire can be safely attacked. The investigation (Leertafel) performed by the fire department, police and Rijkswaterstaat made clear that the decision to enter the tunnel with a fire truck was based on a lot of different aspects in the fire fighting operations. The first arriving fire truck was on the wrong side of the tunnel because it was called for a fire outside the tunnel. Another fire truck was waiting for the barrier to open to enter the tunnel on the safe side. These barriers were not clearly marked which lead to the fact that the wrong barrier opened and the fire truck could not enter the tunnel. By that time a fire truck arrived at the entrance of the tunnel where the fire was. The commander in chief decided to enter the tunnel based on the following facts:

- He could see the fire from the tunnel entrance (300 meter);
- The ventilation system pushed the smoke away from the fire so he could, in a safe way, get close to the fire;
- There were no fire fighters in the tunnel attacking the fire or searching for victims.

The evaluation of this operation learned that three escape doors were blocked so the fire fighters could not enter the tunnel from the safe side to search for victims on the down stream side of the fire during the first search. Later they were able to enter the tunnel and start with the search for victims and the attack of the fire.
Communication between units, dispatches and traffic control was not flawless. Traffic control didn't report the escape door numbers through which the fire department could reach the fire and the fire department didn't ask for it. It was not clear which barriers had to be opened.
At the dispatches the communication between police and fire department can be improved to prevent that some units are called for a fire outside the tunnel and some units for a fire in the tunnel.

CONLUSIONS

- The estimated heat release rate during the fire (between 50 and 60 MW) and the duration of the fire is below the design criteria of the tunnel;
- The tunnel lining performed as expected
- The P.A. system made a smooth evacuation possible;
- The Traffic Controle Centre did not communicate conform procedure, the right (escape)door number to the fire brigade
- The presence of professional (truck and bus) drivers was a benefit to a quick evacuation;
- The longitudinal ventilation system provided an environment where drivers could escape the tunnel and the fire department was able to fight the fire in the tunnel from a short distance.
- In general the procedures from the incident management plans where followed. Where the situation did not exactly fit to the procedures the professionals where by resilliance able to adapt to the situation.

RECOMMENDATIONS

- Better maintenance of tunnel safety measures like escape doors and fire extinguishing equipment is necessary;
- Communication between the three dispatches involved should be improved through training and education and connecting the tunnel camera system to the different dispatches;
- Fire department and Police personal need more training on the use of communication systems when switching between dispatches in different regions of the country;
- Fire Police and Traffic control personal should be trained in procedures as described in the incident management plans;
- Add resilliance to the planning and training system to make the incident management system more robust for unexpected changes

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