Project description and planning of large-scale tests in Runehamar tunnel

August 2003

Prepared by:
Haukur Ingason, SP Swedish National Testing and Research Institute
Anders Löönermark, SP
# Table of content

Table of content ..........................................................................................................................2
1. Introduction ................................................................................................................................3
2. Partners ......................................................................................................................................3
3. Importance of study ..................................................................................................................3
4. Test Programme ......................................................................................................................4
   4.1 Laboratory tests .................................................................................................................4
   4.2 Large scale tunnel tests ..................................................................................................6
   4.3 Measurements ................................................................................................................9
   4.4 Test programme ............................................................................................................12
5. Time table ................................................................................................................................12
1 Introduction

In recent years a number of road tunnels fires have occurred throughout Europe with catastrophic outcome. Among these are the fire in the Mont Blanc tunnel with 39 deads (1999), the Tauern tunnel in Austria with 12 deaths (1999) and the St.Gotthard tunnel in Switzerland with 11 deaths (2001). In these fires the semi-trailer cargo played a major role in the outcome. The main reason being that the trailers contain a very high fire load and the fire could easily spread with aid of the ventilation. The rescue services also had great difficulty in reaching the fire. These fires have prompted the European Union (EU) to fund both a tunnel network (FIT-Fires in Tunnels) and a research project dealing with the question of methods to upgrade the fire safety in existing tunnels (UPTUN-Upgrating Existing Tunnels).

The proposed experiments are unique in that no data of this detail, investigating catastrophic tunnel fires has previously been collected. The tunnel’s unique location, together with its good condition, length and accessibility present one of the few places in the world where such experiments would be feasible. The tunnel is owned by the Norwegian Road Administration and we will work closely with them in performing these tests.

2 Partners

Active UPTUN partners in the performance of the tests will be TNO in Holland and SINTEF/NBL in Norway. Associated partners from USA are the Port Authority in New York, the National Association of State Fire Marshalls in USA (NASFM) and National Institute of Standards and Technology (NIST).

3 Importance of study

The aim of the project is to obtain new knowledge about fire development and fire spread in semi-trailer cargos and the heat exposure to the tunnel linings in the vicinity of the fire. There is a lack of systematic studies of the fire behaviour of semi-trailer cargos. Only two large-scale fire tests using semi-trailer fire loads have been performed in a tunnel. These tests were performed in 1992 in the EUREKA 499 test program performed in Repparfjord in Norway and sponsored by European partners.

One test was performed with a semi-trailer loaded with 2000 kg of furniture and a wind speed of 6 m/s in the tunnel and one test was performed with densely packed wood cribs (2212 kg) supplemented with rubber tiers and plastic materials on the top (322 kg and 310 kg, respectively) and a wind speed of 0.5 m/s in the tunnel. The latter test was a simulated semi-trailer load. In the furniture test, the fire was ignited in a tractor unit (Leyland DAF 310 A) and the fire spread from the tractor unit to the semi-trailer within 10 minutes. After the fire spread from the tractor unit to the semi-trailer cargo the fire developed very rapidly resulting in peak values of 120 – 130 MW within 3-4 minutes, whereas the wood crib tests showed a

---

1 The UPTUN project has 41 partners. The proposed tunnel tests in the Runehamar tunnel are closely linked to this project.
relatively slow fire development. A peak value of 15 MW was obtained 15 minutes after ignition. These two tests show the variation in the results depending on the fuel type, fuel configuration and the wind speed in the tunnel.

In 1993 - 1995, the Massachusetts Highway Department and Federal Highway Administration in conjunction with Bechtel/Parsons Brinckerhoff performed a test program in the Memorial Tunnel in West Virginia, USA, using pool fires (liquid fuel in pans) varying between 20 - 100 MW. The focus of the test programme was primarily on the performance of different types of ventilation systems on smoke control in tunnels as well as foam sprinkler systems on pool fires. The objective was not to study the fire development of semi-trailer cargo or the risk for fire spread between these types of vehicles.

Consequently, a scientifically performed study of semi-trailer cargo fires, including systematic variation in the fuel type, fuel configuration and ventilation conditions as well as the risk for fire spread between these vehicles would provide information of great importance for tunnel authorities, tunnel designers and fire services that is presently lacking.

4 Test Programme

The test programme is divided in Laboratory tests and Large-scale tests. The laboratory tests have been run in SP’s fire hall and the large-scale tunnel tests will be carried out with semi-trailer cargos in the Runehamar tunnel in Norway. The Runehamar tunnel lies about 5 km from Åndalsnes, 40 km south of Molde, in Norway. Molde lies on the Norwegian west coast, about 400 km from Oslo. The tunnel is a two-way-asphalted road tunnel that was taken out of use about ten years ago. It is 1650 m long, 6 m high and 9 m wide, with a slope varying between 1-3 %. The tunnel’s unique location, together with its good condition, length and accessibility present one of the few places in the world where such experiments would be feasible. The tunnel is owned by the Norwegian Road Administration and we will work closely with them in performing these tests. The local Road Administration in Norway will deal with the environmental aspect of the tests.

4.1 Laboratory tests

Several pre-tests consisting of free burning tests under a large hood system at SP’s Fire laboratory have been performed. This was carried out in order to obtain accurate knowledge about the fire behaviour (MW) and heat content (MJ) of the different commodities used in the large scale test program. The commodities we plan to use consist of four different materials, each representing a specific category of material found in the cargo of semi-trailers.

These commodities are standardised wood pallets, plastic pallets made of polyethylene (PE), standardized test commodity consisting of polystyrene cups (PS) in paper cartons and polyurethane madrasses (PUR). These materials do not cover all type of materials found in semi-trailers but they represent basically two categories:

- cellulosic materials (wood, paper)
- synthetic polymers or plastics (PE, PS, PUR).
The burning characteristics such as smoke production, production of toxic gases and heat radiation vary greatly between these materials. Other type of common materials such as vegetables, foodstuff, and margarines are not covered by these two categories. Melted plastics can, however, result in similar fire behaviour as pool fires.

The pre-burn tests were carried out under a large fire collector at SP’s fire laboratory as shown in figure 1. This fire collector can measure the heat release rate (MW), smoke production (optical density, yields etc) and production of hazardous gases (CO, CO₂, HCN etc). We will also be able to measure the total heat content of the commodities used (MJ). The number of tests carried out were three:

- standardised test commodity – cartons with PS cups (80-85/20-15 %)
- mixture of wood pallets and plastic pallets (80-85/20-15 %)
- mixture of wood pallets and PUR (80-85/20-15 %)

Figure 1   Free-burning pre-tests with standardised test commodity – cartons with PS cups under a large hood at SP’s fire laboratory.
In semi-trailer cargos we cannot expect to find only one category of materials, but a mixture of these materials. We also know that the configuration of the commodity may play a major role in the fire development. The semi-trailer load can consists of thousands of different variations or mixtures of materials. In order to reduce the number of parameters between each test, we will keep a constant mass ratio of cellulosic materials (80-85 %) and plastics (15-20%) throughout the test program. This ratio is expected to be a reasonably well-represented mass ratio of what can be found in semi-trailers throughout the world.

Swedish statistics identify 24 different groups of commodity transported on Swedish roads. The combustible commodity can be distributed by their mass ratio into four different categories; cellulosic materials (42 % by mass), miscellaneous commodity inclusive packaging materials (28 %), food products (17%) and oil products (13 %). The two largest categories include cellulosic materials and miscellaneous commodity with packaging materials. The packaging material is usually either cartons or plastics. The statistics do not apportion the miscellaneous commodity with packaging material into cellulosic materials and plastics. Discussions with road carriers indicate that the mass ratio of 80 – 85 % cellulosic materials versus 15 – 20 % plastics is a reasonable distribution for these two categories.

In order to investigate the effects of ventilation on the configuration of the commodity we plan to run some preparatory tests on paper cartons and wood pallets/cribs in order to conduct a scientific evaluation on the effect of ventilation on the large-scale behaviour of the commodity. This is an important parameter to investigate since we know from the literature that authors state that the increase in fire growth rate and peak heat release rates in tunnel fires may be as high as a factor of ten. Therefore, it is importance to investigate these claims before we make a final decision about the configuration of the test commodity.

4.2 Large scale tunnel tests

The heat release rate will be measured with aid of a mobile fan (Mobile Ventilation Unit – MVU 125/140 from Tempest) positioned at one of the tunnel openings. This will provide a means of driving the fire gases in one direction and so enabling the heat release to be measured at the other end of the tunnel. Although the primary objective is to measure the heat release rate for various ventilation conditions, this will also provide important information on:

- how smoke spreads in the tunnel, upstream and downstream of the fire,
- the conditions under which firefighters with breathing apparatus may have to work,
- smoke development from various types of loads,
- gas temperatures and heat fluxes close to the fire place
- the spread of fire between vehicles,
- measuring heat release rates in the 50-200 MW range.

We plan to run four tests with a constant longitudinal velocity of 2.5 m/s and different mixtures of materials in the semi-trailer cargo. In three tests we will use a mixture of cellulose and plastic materials with a mass ratio of approximately 80 - 85 % and 20 - 15 %,
respectively, and in one test we plan to use a “real” commodity consisting of furniture. Below we find a list of the proposed Test Commodity:

- Test Commodity 1 – 600 corrugated paper cartons with interiors (600 mm x 400 mm x 500 mm ; L x W x H) and 15% of total mass of unexpanded polystyrene cups and 40 wood pallets (total weight 2650 kg),
- Test Commodity 2 – 236 wood pallets and 240 PUR madrasses measuring 1000 x 1000 x 150 mm (total weight 6125 kg).
- Test Commodity 3 - 360 wood pallets measuring 1200 x 800 x 150 mm, 20 wood pallets measuring 1200 x 1000 x 150 mm and 75 PE plastic pallets measuring 1200 x 800 x 150 mm (total weight 9917 kg)
- Test Commodity 4 – Furniture (total weight 8400 kg)

Drawings showing the Test Commodity (TC) 1 – 3 are presented in figures A1 – A3 in the Appendix A.

In test 4 we will use furniture similar to that used in the EUREKA 499 test series. The reason for using furniture is that the test carried out in EUREKA 499 was carried out with a very high ventilation rate (6 m/s at the start of the test). Therefore, it is of interest to run one such test for comparison with Test Commodity 2, which has similar materials as in upholstered furniture’s. The longitudinal velocity of 2.5 m/s is what is required in order to avoid long backlayering of smoke upstream the fireplace (test site).

Figure 3 The fire load of the semi-trailer will be located at the centre of one lane of the tunnel.
The fire will be located 560 m from west entrance and the smoke will be blown from east to west. This means that 560 m of the tunnel will be smoke filled. The test commodity will be placed on a simulated semi-trailer up stand (see figure 5) measuring 10700 mm by 2600 mm. The total height will be 4500 mm. We will not use any real trucks as we are focusing on the fire development of semi-trailer cargos and the additional heat release from the hauler unit is expected to be less that 5% of the total heat release. The height of the platform floor will be 1200 mm and the width 2600 mm. The simulated semi-trailer platform will be located at the centre of the left hand lane.

The cross-section of the tunnel at the fireplace is shown in figure 3. The test commodity will be covered by polyethene tarpaulin in all tests. Ignition will take place at the upstream side of the test commodity. It will consist of pieces of fibre board soaked with heptane.

At a distance of 15 m from the downstream side of the test commodity there will be a target consisting of the first row of the same test commodity as used in actual test, see figure 6. We will have video cameras in order to determine the time to ignition of the “second” vehicle.
4.3 Measurements

In this test program SP will measure the gas temperatures, visibility in the smoke, the heat radiation and the toxic gases in the fire gases. There will be other UPTUN partners (TNO in Holland and SINTEF in Norway) making complementary measurements.

In order to carry out the measurements, SP will use a data acquisition system based on radio links to provide wireless broadband communication between the instrument stations and the logging computer. The system has worked very well in other large-scale tunnel tests. The benefits are that we will avoid the need to run long cables in the tunnel. This also provides considerable flexibility in carrying out the work.

There will be three main measuring stations: one located 100 m from the downstream tunnel entrances, one in the vicinity of the fire site, and one 100 m upstream of the fire. In the area between 100 – 400 m from the west (downstream) entrance there will be some measurements on temperatures. The measuring station at the downstream entrance is the one where most of the fire gases will be transported, see figure 6. The upstream measurement station will only be useful when we run a test without any longitudinal ventilation. The results from the entrance stations will be used to calculate the heat release rate with the assistance of the consumption calorimetry technique. The transportation time of the fire gases from the fire site to the measuring location will be corrected afterwards.

There are not only practical reasons to locate these measuring station far away from the fire. We should also expect a quite uniform flow on the downstream side and the temperature is
expected to be low. The drawback is the transportation time but this can be corrected afterwards with the help of CFD calculations and simple mass transport equations.

![Diagram](image-url)

**Figure 6** The layout of the instrumentation along the tunnel.

The measuring station in the vicinity of the fire is more complicated due to the enormous heat. At this site we will only measure gas temperatures and heat fluxes. In figure 8, a proposal for measurements at the fire site is shown. Between 100 m upstream and 463 m downstream of the fire the gas temperature near the ceiling will be measured. At some positions the temperature at a lower level will also be measured (see Figure 6). At 463 m (100 m from the entrance) SP will have the instrumentation as shown in figure 7.

The thermocouples will be type K with 0.25 mm diameter. At some locations near the fire we will measure the temperatures with the Plate Thermometer. The velocity will be measured with aid of bi-directional probes. The gas analysis will be on dry basis and the optical density will be measured with aid of a laser system. The radiation gage will be of Schmidt-Boelter type.
Figure 7  The measurement station 100 m from the downstream entrance. T=gastemperature, u=gasvelocity, O2=oxygen, CO2=carbon dioxide, CO=carbon monoxide, OD=visibility, H=tunnel height at measuring location.

Figure 8  The detailed instrumentation in the vicinity of the fireplace. T=gas temperature, PT=Plate Thermometer, R=heat flux gage

The measurement station 100 m upstream of the fire will be very similar to the one shown in Figure 7, but with fewer velocity measurement and gas analyses.
4.4 Test programme

The preliminary test program is as follows:

<table>
<thead>
<tr>
<th>Test nr</th>
<th>Test Commodity</th>
<th>Estimated heat content (GJ)</th>
<th>Longitudinal ventilation (m/s)</th>
<th>Mass ratio cellulosic/plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TC 2 – wood pallets + PUR</td>
<td>113</td>
<td>2.5</td>
<td>82/18</td>
</tr>
<tr>
<td>2</td>
<td>TC 3 – wood pallets + PE pallets</td>
<td>207</td>
<td>2.5</td>
<td>82/18</td>
</tr>
<tr>
<td>3</td>
<td>TC 4 – IKEA furniture’s</td>
<td>-</td>
<td>2.5</td>
<td>82/18</td>
</tr>
<tr>
<td>4</td>
<td>TC 1 – carton+PS</td>
<td>52</td>
<td>2.5</td>
<td>81/19</td>
</tr>
<tr>
<td>5</td>
<td>TC 1</td>
<td>52</td>
<td>1.5</td>
<td>81/19</td>
</tr>
<tr>
<td>6</td>
<td>TC 1</td>
<td>52</td>
<td>0</td>
<td>81/19</td>
</tr>
</tbody>
</table>

5 Time table

The laboratory tests have been carried out and the preparation of the tunnel will be carried out in August 2003. The tests will be run in September 2003 according to the present test plan. The project is expected to be finalised at end of 2004.

The major financial support comes from the Swedish Rescue Service Agency (SRV), the Swedish Road Administration, the Swedish Rail Administration, the Swedish Research Board (BRANDFORSK) and from the European Commission through the UPTUN project. Industrial sponsors are Promat International N.V. in Belgium, Gerco Beveiligingen B.V. in the Netherlands and B I G Brandschutz Innovationen (TEMPEST) in Germany.
Appendix A - Large scale test commodity

Figure A1 - Test Commodity 1 consists of 600 corrugated paper cartons (600 mm x 400 mm x 500 mm) with interiors and 15% of total mass of unexpanded polystyrene cups and 40 wood pallets.

Figure A2 - Test Commodity 2 consists of 200 wood pallets and 200 PUR madrasses measuring 1200 x 1000 x 150 mm.
Figure A3 - Test Commodity 3 consists of 320 wood pallets measuring 1200 x 1000 x 145 mm and 80 PE plastic pallets measuring 1200 x 800 x 150 mm.