Bus Fire Safety
Rolf Hammarström
Jesper Axelsson
Michael Försth
Patrik Johansson
Björn Sundström
Bus Fire Safety

Rolf Hammarström
Jesper Axelsson
Michael Försth
Patrik Johansson
Björn Sundström*

* Corresponding author bjorn.sundstrom@sp.se
ACKNOWLEDGEMENTS
The authors acknowledge the Norwegian Public Roads Administration and Swedish Road Administration for initiating and financing the project. A large contribution to the project was made by the companies that supplied products for testing. Special thanks go to Volvo AB and Scania AB for providing buses, bus components, information and general assistance.

Brandforsk is also acknowledged for financial support of the computational work presented in chapter 7.
Contents

1 Background 12
  1.1 Project objectives 12
  1.2 Project outline 12

2 Statistical bus fire survey 14
  2.1 Summary 14

3 Interior materials fire risk assessment 15
  3.1 Summary 15

4 Fire risks in buses and coaches 16
  4.1 Why do buses/coaches burn? 16
    4.1.1 Heat 16
    4.1.2 Vibration 16
    4.1.3 Material Fatigue/Malfunction 17
    4.1.4 Inadequate maintenance 17
  4.2 Physical division of risks 17
    4.2.1 Electrical system 17
    4.2.2 Engine compartment 19
    4.2.3 Maintenance 22
    4.2.4 Requests regarding service 24
    4.2.5 Passenger compartment 24
  4.3 Measures to prevent or minimise the effects of fire 24
    4.3.1 Detection 24
    4.3.2 Extinguishing system 24
  4.4 Conclusions 25

5 Test method for room fire partitions 27
  5.1 Conditions 27
    5.1.1 What is fire resistance? 27
  5.2 Why is good fire resistance important? 28
  5.3 Identification of weaknesses in fire resistance 29
    5.3.1 Material 29
    5.3.2 Engine – passenger compartment 29
    5.3.3 Wheel houses – passenger space 29
  5.4 Safety requirements 30
    5.4.1 Breakdown of bus bodies into different fire class zones 30
  5.5 Method 30
  5.6 Testing 31
  5.6.1 Results from the tests 33
  5.7 Layout for the small furnace 35

6 Test method concept for engine compartment fire extinguishment systems 37
  6.1 New test method 37
    6.1.1 Conditions in the engine compartment of a bus 37
  6.2 Design of the test chamber 40
    6.2.1 Description of the layout of test rig 41
    6.2.2 Airflow through the test chamber 42
    6.2.3 The fire sources 43
    6.2.4 Temperature measurement in the test chamber 47
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3</td>
<td>The test procedure</td>
<td>50</td>
</tr>
<tr>
<td>6.3.1</td>
<td>The test set-up</td>
<td>53</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Layout for a test protocol</td>
<td>54</td>
</tr>
<tr>
<td>6.3.3</td>
<td>Experience from tests conducted within this project</td>
<td>55</td>
</tr>
<tr>
<td>6.4</td>
<td>Conclusions</td>
<td>56</td>
</tr>
<tr>
<td>7</td>
<td><strong>Bus fire simulation</strong></td>
<td>57</td>
</tr>
<tr>
<td>7.1</td>
<td>Scenarios simulated</td>
<td>57</td>
</tr>
<tr>
<td>7.2</td>
<td>CFD using Fire Dynamics Simulator (FDS4)</td>
<td>57</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Transport of smoke and fire gases</td>
<td>57</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Smoke production</td>
<td>57</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Fire source</td>
<td>58</td>
</tr>
<tr>
<td>7.2.4</td>
<td>Model uncertainty</td>
<td>58</td>
</tr>
<tr>
<td>7.3</td>
<td>Input to the model</td>
<td>58</td>
</tr>
<tr>
<td>7.3.1</td>
<td>Grid and grid stretching</td>
<td>59</td>
</tr>
<tr>
<td>7.3.2</td>
<td>Initial fire</td>
<td>60</td>
</tr>
<tr>
<td>7.3.3</td>
<td>Material properties</td>
<td>62</td>
</tr>
<tr>
<td>7.4</td>
<td>Results from the simulations</td>
<td>66</td>
</tr>
<tr>
<td>7.4.1</td>
<td>Effect of open roof hatches</td>
<td>66</td>
</tr>
<tr>
<td>7.4.2</td>
<td>Effect of open doors</td>
<td>67</td>
</tr>
<tr>
<td>7.4.3</td>
<td>Effect of distribution of needle felt in ceiling</td>
<td>68</td>
</tr>
<tr>
<td>7.4.4</td>
<td>Grid size analysis</td>
<td>71</td>
</tr>
<tr>
<td>7.5</td>
<td>Conclusions</td>
<td>72</td>
</tr>
<tr>
<td>8</td>
<td><strong>Real scale bus fire tests</strong></td>
<td>73</td>
</tr>
<tr>
<td>8.1</td>
<td>Test Series 1 - Fire in engine compartment with fire detection</td>
<td>74</td>
</tr>
<tr>
<td>8.1.1</td>
<td>Test 1C – Procedure and preparations</td>
<td>74</td>
</tr>
<tr>
<td>8.2</td>
<td>Test 2 - Fire in a wheel house and tyre</td>
<td>77</td>
</tr>
<tr>
<td>8.3</td>
<td>Test 3 - Fire in the rear luggage compartment allowed to develop until flash-over</td>
<td>80</td>
</tr>
<tr>
<td>9</td>
<td><strong>Discussion, conclusions and recommendations</strong></td>
<td>100</td>
</tr>
<tr>
<td>9.1</td>
<td>Statistical evidence</td>
<td>100</td>
</tr>
<tr>
<td>9.2</td>
<td>Reduced fire risk through improved interior materials</td>
<td>102</td>
</tr>
<tr>
<td>9.3</td>
<td>Reduced fire risk by improved design, routines, and materials</td>
<td>104</td>
</tr>
<tr>
<td>9.4</td>
<td>Reduced fire risk by improved fire resistance</td>
<td>105</td>
</tr>
<tr>
<td>9.5</td>
<td>Reduced fire risk by fire fighting in engine compartment</td>
<td>105</td>
</tr>
<tr>
<td>9.6</td>
<td>Reduced fire risk by computer aided design</td>
<td>107</td>
</tr>
<tr>
<td>10</td>
<td><strong>Appendix 1 – Calculation of thermal inertia and ignition temperature for needle felt</strong></td>
<td>108</td>
</tr>
<tr>
<td>10.1</td>
<td>Experimental setup</td>
<td>108</td>
</tr>
<tr>
<td>10.2</td>
<td>Results and analysis</td>
<td>109</td>
</tr>
<tr>
<td>11</td>
<td><strong>References</strong></td>
<td>111</td>
</tr>
</tbody>
</table>
Preface

The project presented in this report was initiated and financed by the Norwegian Public Roads Administration and Swedish Road Administration.

The project was managed by SP Technical Research Institute of Sweden, Department of Fire Technology.
Executive summary

Between 1999 and 2004 an average of 49 bus and coach fires were reported each year in Norway, and 122 per year in Sweden. However, it can be assumed that the actual number of fires is considerably higher than this, as a large number of fires are not reported. This means that about 1.0-1.4 % of all buses and coaches in service are involved in fires each year. In percentage terms about 5-10 times as many buses and coaches catch fire as do heavy goods vehicles. Fortunately, despite the surprisingly high number of fires, injuries to persons have been very limited. However, the risk of a catastrophe is high if, for example, a fire should occur in a situation where escape is difficult. Examples of such cases are: Poland in 2005, when 13 persons died and Sweden in Fjärdhundra accident in 1998 and that in Arboga in 2006 where luckily no fatalities occurred. As recently as November 2008 a bus fire in Germany killed 20 persons.

In the first experimental part of the project a number of materials typically used in the interior of buses were reviewed in terms of their fire performance. The tested materials were three seats, eleven wall and ceiling materials and two floor systems coming from modern buses and coaches with a mass more than five tons and with more than 22 passenger seats. All materials were tested according to ISO 3795/FMVSS 302, a simple horizontal flame spread fire test presently required for buses and coaches in Europe, and in several state-of-the-art fire test methods used for other applications such as trains, ships and buildings. The tests aimed to evaluate flame spread behaviour, heat and smoke release rates, ignition resistance and generation of toxic gases. The test results were compared to existing criteria for other applications and the present level of fire safety was discussed. The main conclusion was that the present horizontal fire test does not provide a sufficiently high level of fire safety in the passenger compartment of buses. Further, other fields with fire performance requirements are typically much more stringent. For example, products fulfilling the horizontal test for buses would not even meet the lowest performance level for buildings. A short review of the scientific literature shows that several publications have come to the same conclusion.

Since it was clear that the ISO 3795/FMVSS 302 test method is inadequate for discriminating between different levels of fire performance, an initiative has been taken at GRSG (Groupe de rapporteurs sécurité générale) at UNECE (United Nations Economic Commission for Europe) to address this issue. The aim is to amend Regulation No. 118 where it is specified that ISO 3795/FMVSS 302 is the test to which bus interior materials should comply. The proposed amendment contains other and better methods that are employed by IMO (International Maritime Organization) and in the new EN-standard for fire safety of trains.

One part of the project was to identify designs and routines that create high risk for fire, and means to mitigate these risks. Fires are typically a result of heat, vibrations, defective maintenance, and compromises in the design. Most fires start in the engine compartment and therefore actions to reduce fire risk were focused on this part of the vehicle. Examples of suggested actions were:

- Insulate all hot surfaces in the engine compartment (thermal insulation).
- Equip the engine compartment with better detection systems in combination with fire extinguishing systems.

If a fire occurs in, for example, the engine compartment or in a wheel it is important to contain it and delay spread of smoke and fire to the passenger area. The ability of a construction to resist spread of smoke and fire is referred to as its fire resistance. A high fire resistance in the critical partitions of the bus translates directly into more time for safe evacuation of passengers. Moreover, a high fire resistance will reduce the overall
expected damage and therefore also reduce costs for repair and due to downtime. Typically fire resistance is tested according to the standard EN 1363-1 which is an advanced full scale test that is relatively costly. An alternative new small scale test method for fire resistance of bus partitions is suggested. This will enable cost effective testing in the early phase of development. In brief the suggested method consists of a furnace with dimensions W x H x D = 120 cm x 100 cm x 80 cm that is heated with three LPG-burners. The properties studied during the test are thermal insulation and integrity of the partition. A number of materials were tested with this new method. The results show that the method is effective in quantifying insulation capacity and integrity.

In addition to the method for testing partitions a new method for testing fire extinguishment equipment in the engine compartment was developed. The purpose was to define a test that can evaluate the fire fighting performance of different extinguishment systems in a well defined and objective way. The proposed test consists of a reduced scale engine compartment, scale 1:3, configured in a similar manner as that of a city bus with a rear engine. Since the scale of the test compartment is 1:3 only one third of the nozzles should be used in the test compartment, as compared to the number used in the full scale end application. Three different fuels are used at different positions in the test engine compartment: fibrous, liquid, and gas, and three different operating conditions are simulated: full load, idling, and engine off. The operating conditions are set by setting a pre-defined temperature on the engine mock-up and on the exhaust system mock-up, and by using different forced ventilation inside the test engine compartment. The proposed test method can be useful for manufacturers of fire fighting equipment, especially in the developmental phase. It can also be useful for bus owners and manufacturers by allowing an objective comparison of the performance of any given system and an objective definition of the required capacity of the system.

One part of the project was to investigate to what extent CFD (Computational Fluid Dynamics) models can be used as a complement to full scale fire tests. It was shown that CFD modelling can be particularly useful when the movement of smoke and heat inside the bus is the object of the study. Simulation results should be interpreted carefully, however, by a trained professional and cannot presently be used as an alternative to experiments, but rather as a complement. The reason for this is that there are many unknown parameters affecting the simulations. Experiments are therefore needed in order to validate and help interpret the simulation results.

In the last part of the project a conventional coach for 49 passengers was used for three different real scale tests. The tests were:
- Fire in the engine compartment
- Fire in a tyre
- Full scale fire of the entire coach

In the first test a fire was started in the engine compartment. The bus was equipped with a system for fire detection which was tested at the same time. The main conclusion was that stopping the engine is an effective way of reducing or extinguishing the fire since the oxygen level drops rapidly when ventilation of the engine compartment stops. It was also found that the detection system enabled an early detection which in practice would drastically reduce any damage to the engine compartment and eliminate or reduce spread of fire and smoke to other parts of the bus when coupled to rapid fire intervention.

The test with a burning tyre did not result in a cracked window. This was an interesting result since fire spread from a tyre into the passenger area via a broken window is often believed to be the root cause of fire inside the bus. One should note, however, that the tested vehicle was a coach where the distance from the tyre to the window is larger than for a typical city bus. This means that for the tested coach the flames did not reach the
window to the same extent as would be the case for many other bus types. Smoke and fire
did spread to the passenger area, however, from the wheel house via the floor and side
wall.

In the last test a fire was allowed to develop in the entire bus. The heat release rate
reached 12 MW before the fire was extinguished in order to protect the laboratory
equipment. The scenario was a fire starting in the engine compartment in the rear end of
the coach. The purpose with this test was to study:

− Fire development from the engine compartment into the passenger compartment.
− Smoke spread and visibility in the passenger compartment.
− Concentrations of toxic gases in the passenger compartment.
− Heat release rate from a developed fire in the coach.

The test showed that the time for evacuation of the passengers was 4 – 5 minutes at a
maximum. After this time the concentration of toxic gases reached dangerous levels.
The visibility in the passenger compartment decreased rapidly. After 5 – 6 minutes the
visibility was just a few meters.

In summary, the number of bus fires is disproportionately high as compared to other types
of vehicles. In this project a number of strategies for improving the fire safety of buses
have been defined. A new test method for partitions of buses has been developed and is
promoted internationally. This test will considerably simplify testing as compared to
existing methods. A method for testing fire fighting equipment in engine compartment
has also been developed.

A full scale test showed that the time available for evacuation in the case of fire is very
short. Therefore, improvement of the fire behaviour of buses is of the highest importance
to ensure passenger safety in the future.
1 Background

The number of bus fires is large and there is a potential for catastrophic consequences when fires occur in conjunction with a bus crash. Recently in Poland a crash followed by a severe fire killed 13 young people and injured 40. The materials, structures and design of the buses/coaches used today does not ensure an acceptable level of safety to fire. Therefore the Norwegian and the Swedish Road Administrations initiated a research project together with SP Technical Research Institute of Sweden on bus fire safety.

1.1 Project objectives

The main objective of the project is to decrease the number and consequences of bus fires. This will be accomplished through generation of knowledge about fire cause and fire development in buses. These results will be used to develop specific recommendations for test methods and regulations to increase the fire safety of buses.

1.2 Project outline

The project covers a wide range of fire safety issues in buses. The main focus is on: risk assessments, performance requirements for interior materials and the study of fire risks, prevention, detection and extinguishment in engine compartments. Below is a short summary of the main activities presented in this report:

- **Statistical survey of bus fires in Norway and Sweden**
  A survey of the number of fires including fire causes and consequences during the last 10 years.

- **Fire tests of interior materials and seats in buses**
  A test series was performed using a number of well established fire test methods and comparison were made with existing requirements for e.g. buildings, trains and ships.

- **Fire risks of buses and coaches**
  Identification of fire risks by studies of bus construction/design, maintenance and economic aspects.

- **Test method for fire partitions**
  Study and proposal of a relevant test method to evaluate the fire barriers between engine and passenger space.

- **Test method concept for engine compartment fire extinguishing systems**
  Development of a repeatable test method for evaluation of extinguishing systems in the engine compartment.

- **Fire simulations**
  Computer simulations of real-scale fires to illustrate fire development and smoke spread in the bus. The results can be used for evacuation assessment.

- **Real-scale fire test of a coach**
  A complete coach was tested in real scale in the SP burn hall. The test included, e.g., measurement of Heat Release Rate (HRR) and smoke production during the fire.

- **Conclusions and proposals for improved fire safety**
  Finally all the actions for proposed new methods and requirements for improved fire safety on buses are summarized.
2 \hspace{1em} \textbf{Statistical bus fire survey}

The results of this survey are reported in: Bus and coach fires in Sweden and Norway, SP Report 2006:26, ISBN 91-85533-11-4, ISSN 0284-5172, Borås 2006. A summary of the results is provided below.

2.1 \hspace{1em} \textbf{Summary}

Between 1999 and 2004, an average of 49 bus and coach fires were reported each year in Norway, and 122 per year in Sweden. However, it can be assumed that the actual number of fires is considerably higher than this, as a large number of fires are not reported. This means that about 1.0-1.4 \% of all buses and coaches in service are involved in fires each year. Media have drawn attention to the problem, and the insurance sector, together with the bus and coach industry, have taken steps to break the rising trend. Nevertheless, the number of fires is still at a high level as, in percentage terms, about 5-10 times as many buses and coaches catch fire as do heavy goods vehicles.

Fortunately, despite the surprisingly high number of fires, injuries to persons have been very limited. However, the risk of a catastrophe is high, if a fire should occur in a situation where escape is difficult. An example of such a case occurred in Poland in 2005, when 13 persons died. Sweden has seen several examples of major bus fires in recent years that have fortunately not resulted in any fatalities, such as the Fjärdhundra accident in 1998 and that in Arboga in 2006.

Both Norway and Sweden have seen a noticeable rise in the number of bus and coach fires between 1998 and 2001. The level in Sweden then stabilised, while the number of bus and coach fires in Norway shows a slightly declining trend. The reason for the rise over the 1998-2001 period is strongly linked with the more stringent noise regulations that were introduced on 1st October 1996.

The data presented is collected from other reports, internet searches and contact with other sources and public authorities such as insurance companies, bus and coach builders and operators, and the National Board of Civil Defence, Rescue and Fire Services. A recurring feature throughout the process of information acquisition was that of poor documentation, with the result that there are many unknown aspects in each fire. The main causes of fires in buses and coaches have been seen to be electrical faults and leakage of flammable liquids.

The actual number of fires per year is an estimate, based on material from the reported cases and on information from those responsible for insurance assessment of fires in vehicles. The unreported cases can, for example, consist of incidents below the insurance excess values, or of cases dealt with under the manufacturer’s or builder’s warranty.

For more information, see chapter 9.1
3 Interior materials fire risk assessment


3.1 Summary

A number of materials typically used in bus interiors were reviewed for fire performance. Data is presented from fire tests made on three seats, eleven wall and ceiling materials and two floor systems coming from modern buses and coaches with a mass more than five tons and with more than 22 passenger seats. All materials were tested in ISO 3795/FMVSS 302, the simple horizontal flame spread fire test presently required for buses and coaches in Europe, and in several state-of-the-art fire test methods used for other applications such as trains, ships and buildings. The tests aimed to evaluate flame spread behaviour, heat- and smoke release rates, ignition resistance and generation of toxic gases. The test results were compared with existing criteria for other applications and the present level of fire safety is discussed.

A short review of other research within the same area shows that several other publications have come to the same conclusion.

An obvious conclusion from the results in this report is that ISO 3795/FMVSS 302 is inadequate when it comes to discriminating between different levels of fire safety performance of interior materials for buses. Therefore an initiative has been taken at GRSG (Groupe de rapporteurs sécurité générale) at UNECE (United Nations Economic Commission for Europe) to address this issue. The aim is to amend Regulation No. 118 where it is specified that ISO 3795/FMVSS 302 is the test to which bus interior materials should comply. The proposed amendment will contain other and better methods that are presently employed by IMO (International Maritime Organization) and in the new EN-standard for fire safety of trains.

As recently as November 4th 2008 a tragic bus fire occurred in Germany with 20 fatalities. The fire appears to have started in the toilet area and then rapidly spread inside the passenger compartment. This accident clearly shows the need for good fire safety performance of bus interior materials.

For more information, see chapter 9.2
4 Fire risks in buses and coaches

4.1 Why do buses/coaches burn?

This section focuses on identifying weak design, system solutions, routines, etc., which create high fire risks.

Isolated events seldom lead to a fire, but more often the combination of several events. Development of the vehicle means taking a wealth of product development requirements, functions and properties into account, and the final product is therefore often a compromise. There are lots of dangerous combinations that can lead to a fire, which are not always fully understood or treated fully. It is not only the design of the new product that determines whether the fire risk is high. When the bus reaches the customer, maintenance of the product is at least equally important in terms of preventing fires.

Apart from arson, there are a few common reasons for the ignition of buses or coaches, i.e.:

1. Heat
2. Vibration
3. Material fatigue/Malfunction
4. Inadequate maintenance

Most bus fires start in the engine compartment or surrounding areas. In addition, fire can start in the electrical system in the bus and the wheel houses. Lastly, arson can start a fire anywhere on the bus.

4.1.1 Heat

There must be heat to start a fire and keep it burning. The potential of a material to ignite is also proportional to the temperature. This is compounded by the fact that heat causes accelerated ageing of most organic materials such as polymers.

The proportion of polymeric materials in today's vehicles is very high. Different materials have different sensitivities to temperature, and decomposition processes will differ substantially from case to case. A rough rule of thumb for a polymer product is that life is halved when the average temperature increases by 10°C. This was seen clearly in the years 1998 - 2001, when the number of soundproofed engine compartments on the market increased. The acoustic insulation also provided a good thermal insulation. The temperature rose in the engine compartments, and the endurance of many parts was shortened considerably.

4.1.2 Vibration

Vibration is created by, e.g., the vehicle's engine and wheels in contact with the roadway. Vibrations and other frequent movements are a large part of the reason why tubes and other vehicle components develop fatigue cracks, break, and leak flammable liquid, or why electrical systems' insulation gets worn and a short circuit is created. Vibrations accelerate existing degradation processes of parts.
4.1.3 Material Fatigue/Malfunction

Narrow inaccessible spaces preventing both physical and visual access is a potential source of a fire. Poor ventilation often leads to high temperatures, which in turn reduces the lifespan of sensitive details. Material selection that is driven by economics (or ignorance) rather than performance, will also create future problems. The list of issues to be considered in the construction process is long and there are many things to consider.

There are many legal requirements limiting how a bus should look and what properties should be fulfilled. In addition to these requirements, the market places demands (users and clients) which further complicate the situation when a bus is developed. This, together with competition with other bus manufacturers, means that engineers in the design process must make a variety of compromises in order to achieve their goals.

One example is in city buses, where passenger space and a low, flat floor (low step access) have been prioritised. This has resulted in very compact engine compartments, which in turn makes accessibility and maintenance more difficult. Another example is updates and facelifts on older bus models, where many new parts need to fit into a severely confined space due to, e.g., the need for a bigger engine, air conditioning systems with higher performance, larger filters for longer service intervals, etc.

4.1.4 Inadequate maintenance

Lack of maintenance is a source of many fires. In many cases maintenance can be good but does not include a thorough consideration of the consequences of fire risks. Maintenance should therefore be viewed as: service combined with fire risk assessment and mitigation.

4.2 Physical division of risks

Below is a physical division of risks throughout the various areas in a bus. The risk areas are divided into: electrical system, engine compartment, maintenance, passenger compartment and arson.

4.2.1 Electrical system

Fires caused by electrical failure constitute a relatively large proportion of the total number of fires. A modern bus contains kilometres of cable and many contact points. Therefore the fire risks are high.

The electrical system can develop heat, so the basic principle is that cables should be kept strictly separate from fuel hoses, hydraulic cables and any flammable liquids and gases. In addition, an electrical system should be treated in such a way that the risk of heat build-up is kept very low.

4.2.1.1 Risk factors in the electrical system

**Heat Damage:** Heat accelerates ageing resulting in fatigue and potential malfunction of parts such as insulating materials (plastics, rubber etc.)

**Mechanical effect:** Collisions and vibration cause mechanical damage such as wear and tear and clamp damage. Contacts with sharp edges may cause short circuits. Soldered copper becomes harder and is therefore at greater risk of fatigue breakage due to mechanical vibration. Clamping of cables should be done very carefully.
**Chemical agents:** Moisture mainly gives rise to problems such as contact resistance, depending on oxidation. Sparking can occur in the connector, which in some cases develop into arcs, accelerating the decomposition and increasing the potential for ignition. Dust on insulation materials can develop into carbon bridges, causing leakage currents and, in some cases, arcs.

**Fuses:** A thermally insulated fuse with high load can be a fire hazard. Fuses carrying more than 75% of their rated current produce heat.

**Blade Fuses:** This is the most common fuse type in the vehicle industry. One problem is that they have the same dimensions regardless of rated current. There is therefore no guarantee that a replacement fuse is of the same or lower rated current.

**Unsecured cables:** Cables between the generator and battery are usually unsecured. To avoid shortcuts they must be properly insulated.

**Cable Design:** Today's vehicles contain kilometres of cable compared to vehicles 25 years ago. To keep down weight and cost, the trend is to reduce cable cross-sections to smaller dimensions. This poses a greater fire risk in case of incidents or unforeseen overload. If the cables are thermally insulated and the ambient temperature is high, the risk of melting damage in the cable insulation increases.

### 4.2.1.2 Prevention of fires due to electrical failure

Since fires caused by electrical failure represent a relatively large proportion of the total number of fires, preventative measures will be effective in eliminating or mitigating harm.

If the power can be broken quickly in the circuit that causes or maintains the fire, the fire may extinguish by itself or slow down. Since fuses are no guarantee that a fire will not occur or spread, a modern electrical system should be equipped with a sensor/scanning system which indicates error, and switches off the current without the bus becoming impossible to drive. The security level should be set at different levels for the specific system, i.e., between breakable and non-breakable sub-systems.

Electrical motors that are stopped or move slowly may load the electrical system with such a strong current that fire breaks out. The circuit containing the electrical motor should therefore be equipped with a resistive current limitation.

When the bus leaves the manufacturer or the bodyworks, it will be customized with extra equipment and accessories for future needs. Adding connection blocks with fuse holders at strategic locations in the bus from the outset will facilitate and ensure the quality of these installations. It will also help simplify wiring if they have a heavy load (VP wires or similar).

Cable ties or strips, made of thermoplastic, are often used to fasten cables, hoses, components etc. The material ages, cracks and loses its functionality in the warm climate of the engine compartment. Although the manufacturer delivers cable ties of the appropriate quality, it is not always certain that the same quality will be used in repairs. It would therefore be useful if the ties were marked with a maximum working temperature to ensure a working lifetime of, for example, 10-15 years.
4.2.2 Engine compartment

High temperatures, hot surfaces and a variety of combustible materials make the engine compartment a high risk area. This means that the engine compartment design, including parts, must be of a high standard and quality to ensure a low fire risk.

4.2.2.1 Risk factors in the engine compartment

The engine compartment contains combustible materials in the form of gases, liquids and solids. If material come into contact with a hot surface due to a leak or some other action, a fire can occur. Two characteristics can be used to assess the risk level of any given material, i.e.:

1. Flash point
2. Autoignition temperature:

Flash point

This is the temperature at which the liquid spontaneously forms a combustible mixture of gases in the air. Flammable liquids are divided into different classes according to their flash point. The flash point is useful for risk assessment of a flammable liquid. Table 1 gives the flash point classification of some liquids.

<table>
<thead>
<tr>
<th>Class</th>
<th>°C</th>
<th>Type of liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 *</td>
<td>&lt; 21</td>
<td>Petrol, ethanol and methanol (concentrated washer fluid)</td>
</tr>
<tr>
<td>2a</td>
<td>22 – 30</td>
<td>Ethanol in water solution 30-70 weight percentage</td>
</tr>
<tr>
<td>2b</td>
<td>31 - 55</td>
<td>Aviation kerosene and similar products, such as naphtha products, turpentine oil, white spirit</td>
</tr>
<tr>
<td>3</td>
<td>56 - 100</td>
<td>Diesel oil and light fuel oil</td>
</tr>
<tr>
<td>Unclassified</td>
<td>&gt; 100</td>
<td>Heavy fuel oil, hydraulic oil, engine oil, RME, etc.</td>
</tr>
</tbody>
</table>

* Class 1 should be labelled "Extremely flammable" if the flash point is < 0°C, which is the case for normal petrol, and "Highly flammable" for other class 1 liquids/gases.

Autoignition temperature

This is the temperature at which the substance ignites spontaneously, without an external ignition source. The autoignition temperature may vary depending on the method of measurement.

A substance can also be assessed on the basis of other characteristics, such as the concentration for combustion (combustibility range). In section 4.2.2.2 a brief summary of such data for engine area materials is given.
4.2.2.2 Flammable material in the engine compartment

In the engine compartment, there are combustible materials in the form of solid, liquid and gaseous substances. Combustible materials in solid form include: plastics, rubber and cellulose in the form of plywood and acoustic absorbers. Table 2 to Table 5 below give examples of flammability properties for different materials commonly found in the engine compartment divided into gases, liquids, solid and fuels.

### Table 2. Fire data for gaseous substances at room temperature

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG [Liquified Petroleum Gas] (also known as LP Gas, or autogas)</td>
<td>- 104</td>
<td>430 - 580</td>
<td>2 – 10</td>
<td>Very high</td>
</tr>
<tr>
<td>Propane [C₃H₈]</td>
<td>- 108</td>
<td>450</td>
<td>2,2 – 9,5</td>
<td>Very high</td>
</tr>
<tr>
<td>Butane [C₄H₁₀]</td>
<td>- 60</td>
<td>405</td>
<td>1,5 – 8,5</td>
<td>Very high</td>
</tr>
<tr>
<td>CNG [Compressed Natural Gas] (The main part is methane [CH₄])</td>
<td>- 188</td>
<td>580</td>
<td>5 – 15</td>
<td>Very high</td>
</tr>
<tr>
<td>Hydrogen gas [H₂]</td>
<td>- 253</td>
<td>560</td>
<td>4 – 75</td>
<td>Extremely high</td>
</tr>
<tr>
<td>Ethylene gas [C₂H₄]</td>
<td>- 100</td>
<td>425</td>
<td>2,7 – 36</td>
<td>Extremely high</td>
</tr>
</tbody>
</table>

LPG consists mainly of propane (C₃H₈) and butane (C₄H₁₀). In the Nordic countries, the proportion is 96/4 all year round. A high percentage of propane is needed in colder areas, while the opposite is true in warmer areas. LPG is heavier than air and can therefore accumulate in low-lying areas. Installation without leaks and good air ventilation in the storage and use spaces is therefore important to minimise the fire risk.

### Table 3. Fire data for liquid substances at room temperature

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel oil</td>
<td>55</td>
<td>220</td>
<td>0,6 – 6,5</td>
<td>High</td>
</tr>
<tr>
<td>Engine oil mineral</td>
<td>170 - 220</td>
<td>350</td>
<td>-</td>
<td>High</td>
</tr>
<tr>
<td>Engine oil synthetic</td>
<td>220</td>
<td>-</td>
<td>-</td>
<td>High</td>
</tr>
<tr>
<td>Gear box oil</td>
<td>220</td>
<td>350</td>
<td>-</td>
<td>High</td>
</tr>
<tr>
<td>Servo oil</td>
<td>170 - 220</td>
<td>350</td>
<td>-</td>
<td>High</td>
</tr>
<tr>
<td>Brake fluid</td>
<td>175</td>
<td>350</td>
<td>-</td>
<td>High</td>
</tr>
<tr>
<td>Glycol (sugar)</td>
<td>111</td>
<td>410</td>
<td>-</td>
<td>Medium</td>
</tr>
<tr>
<td>Spirit (96% ethanol)</td>
<td>12</td>
<td>425</td>
<td>3 – 19</td>
<td>Very high</td>
</tr>
</tbody>
</table>

**Autoignition temperature**

Usually a higher temperature is needed for a hot surface in contact with the liquid in order for it to ignite, than if the liquid is heated homogeneously. This is because energy is taken from the hot surface when the liquid is heated and evaporates. For thin exhaust pipes, the temperature can therefore fall below the liquid's autoignition temperature before the
liquid itself reaches this temperature. In this case, the gas formed from evaporation of the liquid will not ignite. However, contact between flammable liquids and the hot exhaust system is a very common cause of the fire in engine compartments.

In table 3 below typical surface temperatures for exhaust systems, to ignite different combustible liquids are summarised.

Table 4. Ignition Temperatures for typical engine fuels (empirical data)

<table>
<thead>
<tr>
<th>Material</th>
<th>Necessary surface temperature to ignite the fuel [ °C ]</th>
<th>Auto ignition temperature [ °C ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>520 – 620</td>
<td>400</td>
</tr>
<tr>
<td>Diesel</td>
<td>520 – 550</td>
<td>220</td>
</tr>
<tr>
<td>Engine oil</td>
<td>350 – 600</td>
<td>350</td>
</tr>
<tr>
<td>Brake fluid</td>
<td>410 – 500</td>
<td>350</td>
</tr>
</tbody>
</table>

4.2.2.3 Heat and environmental resistance

Heat is produced by the combustion in the engine and transported out through the engine exhaust system and engine body. Exhaust pipes have temperatures of up to 600°C, and the engine body is generally approx. 95°C. The air temperature in an engine compartment is normally around 70 - 90°C, which is higher than the flash point for both diesel and ethanol, which means that both liquids are easy to ignite in an engine compartment. For a heavily-loaded engine, high outdoor temperatures and poorly ventilated engine compartment means that the air temperatures can increase to even higher levels.

The high temperatures in the engine compartments have a strong heat-ageing effect on all polymer materials, and a particular problem is the rapid heat ageing of the fasteners (cable ties or strips). The combination of a sound insulation (which also provides thermal insulation) in the engine compartment, poor ventilation due to the engine cooler on the roof, and high outdoor temperatures can combine to give a higher temperature in the engine compartment, and put extra high demand on fasteners made of plastic.

Table 5. Temperature data for solids

<table>
<thead>
<tr>
<th>Solid fuels</th>
<th>UL¹ temperature [ °C ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE (PolyTetraFluoroEthylene)</td>
<td>180</td>
</tr>
<tr>
<td>PA6 (PolyAmide 6)</td>
<td>65</td>
</tr>
<tr>
<td>PVDC (PolyVinylidene Chloride)</td>
<td>-</td>
</tr>
<tr>
<td>PC (PolyCarbonate)</td>
<td>115</td>
</tr>
<tr>
<td>PS (PolyStyrene)</td>
<td>50</td>
</tr>
<tr>
<td>PET (PolyEthylene Terephthalate)</td>
<td>130</td>
</tr>
<tr>
<td>PVC (PolyVinyl Chloride)</td>
<td>50</td>
</tr>
<tr>
<td>PMMA (PolyMethyl MethAcrylate)</td>
<td>50</td>
</tr>
<tr>
<td>POM (PolyOxiMethylene)</td>
<td>85</td>
</tr>
<tr>
<td>PP (PolyPropylene)</td>
<td>80 – 115</td>
</tr>
<tr>
<td>HDPE (High Density PolyEthylene)</td>
<td>50</td>
</tr>
</tbody>
</table>

¹ The UL temperature specifies the maximum temperature that the material can work continuously at without selected properties changing more than 50% in typically 4-5 years. Examples of measured properties are impact strength, breaking strength and dielectricity. Ref: Plaster materialval och materialdata (Plastics materials and materials data) - Carl Klason and Josef Kubát
The temperature can also cause rubber to age. Mechanical stresses, ozone, oils and vibration can also shorten the life of rubber. The effect of temperature on different engine materials is summarised in Table 6.

Table 6. Heat and ozone resistance of various engine materials

<table>
<thead>
<tr>
<th>Product</th>
<th>Temperature durability</th>
<th>Ozone durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR Natural rubber</td>
<td>10 – 20 years</td>
<td>5 – 10 years</td>
</tr>
<tr>
<td>CR Chloroprene Rubber</td>
<td>100 °C</td>
<td>110 °C</td>
</tr>
<tr>
<td>NBR, Nitrile butadiene rubber</td>
<td>100 °C</td>
<td>110 °C</td>
</tr>
<tr>
<td>EPDM Ethylene propylene diene</td>
<td>100 °C</td>
<td>110 °C</td>
</tr>
<tr>
<td>M-class rubber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AEM. Ethylene Acrylic Rubber</td>
<td>150 °C</td>
<td>160 °C</td>
</tr>
</tbody>
</table>

To demonstrate the risks of elevated temperatures in an engine compartment, we can make use of a method that has been developed by Arrhenius. Highly simplified, the endurance of polymer materials is estimated to the half of the time when the temperature increase 10ºC. However, this provides a rule of thumb for estimating the effect of increased temperature on specific materials and should not be used for more than 20-30ºC, outside the tested temperatures.

4.2.2.4 Vibration

All the parts attached to the engine vibrate with the engine. New or modified features on an engine must be tested carefully before being put into production\(^2\) to ensure that they can withstand the continual vibration in a working engine.

Anchoring of cables, hoses and tubes is an important part of maintenance. As stated in section 4.2.2.3 it is also of great importance that the fastening elements (staples, cable ties, stripes, etc.) are of the appropriate quality to ensure their reliability for the whole of their expected working lifetime.

4.2.3 Maintenance

The level of maintenance is one of the more important factors in preventing fires. There are many ways fire can be avoided with the right kind of maintenance. Service in combination with risk assessment ensures that the correct steps are taken to mitigate any risks identified. This means that a service is not fulfilling its purpose if we only change the oil and filter and check fluid levels in the parts made easily accessible by the manufacturer. The other parts of the engine compartment must also be checked through visual and physical inspection, and a risk assessment of items that need to be addressed should be made and followed. As part of this process the following issues should be considered:

- Maintenance time
- Accessibility
- Repairs and workshop visits
- Who carries out the service.

\(^2\) For example, oil filters changed to a larger size / longer length to allow more time between filter replacement. The increased mass of the oil filter in combination with the engine's movement led to fatigue breakage and the leakage of engine oil.
4.2.3.1 Maintenance time
Full service for a coach can take 6 hours, while a city bus may need 8 hours and a (city) gas bus may require an additional 50% more time, depending on all the safety systems that need checking. In order to carry out service and repair of buses for intercity services, up to 10% extra buses will be needed in a fleet.

4.2.3.2 Accessibility
Many of today's city buses have such compact engine compartments that both inspection and access are severely limited. Maintenance therefore takes extra long time due to a lack of space and access difficulties. Some parts of the engine are only accessible from the top (from inside the bus) through gaps that severely restrict work areas. It is therefore quite possible that some checks are consciously or unconsciously eliminated. Poor accessibility therefore increases the time to conduct maintenance and decreases its quality, which also increases the risk of fire.

4.2.3.3 Repairs and workshop visits
Fires occurs quite frequently after workshop visits. This is not statistically verified, but confirmed by anecdotal evidence from many quarters. Economic demands lead to cuts in maintenance organisations and very few extra buses. This in turn provides very small margins, and places high demands on both personnel and material.

Work carried out under uncomfortable working conditions with limited space, poor visibility, where there is a risk of injury (due to hot surfaces and sharp edges) and where time is short increases the risk of mistakes and the frequency of incidents.

In some cases engine compartments are designed in a service-friendly way. This means that reading fluid levels and filling of liquids is easily carried out. This is unfortunately not universally true and there are also many places on a bus which are very inaccessible, both visually and physically. There are many examples of repairs where, for various reasons, a part has been mounted incorrectly because of poor accessibility or lack of time, e.g., a tube is not fastened in the right place, cables are installed with long free lengths, etc. This can increase the risk of vibrations affect parts, and mechanical fatigue leading to breakage and leaks. Damage to cable insulation because of wear, e.g., is common in these contexts.

A faulty risk assessment or misjudgement of the situation due to lack of time or bad judgment can be disastrous. A small leak can grow and become larger if not resolved in time. Loose nuts and bolts that are not addressed can easily lead to parts becoming detached and causing damage, which in turn can lead to fire. A tube of polymeric materials may have aged because of the high heat, and become hard and brittle. If not replaced in time, a leak may arise, which in turn leads to fire.

4.2.3.4 Who carries out the service
As recently as 10-15 years ago, it was very common for bus companies to have their own service centres, and this is still often the case. However, we can see a new trend emerging whereby the buses are leased directly by the manufacturer or its sales organisation, meaning that a package of bus and service is bought. The manufacturer still owns the bus and services it at specified intervals. If the bus is not brought in on the specified service dates, the owner's warranty is reduced. This new trend has a positive effect in that the buses have better care, and the number of fires will probably be reduced in the long term.
4.2.4 Requests regarding service

An idea which has been promulgated within this project to improve conditions for maintenance could be to investigate whether the engine package (on the underlying engine) could be made removable in a simple way. This would improve accessibility meaning that the service time could be reduced and service quality increased in the same operation.

4.2.5 Passenger compartment

Fires in the passenger compartment are often triggered by an electrical fault or are the result of spread of fire from the engine compartment. However, arson is also a common source of fires in the interior materials and correspond to 5% of all bus fires. The major problem with fires in the passenger compartment is that the interior material can have a very low fire safety permanence. This means that a source like a burning newspaper can create a fire that rapidly produces a lot of smoke which makes evacuation difficult. Better test methods for interior materials is a prioritised working area for future bus regulations.

4.3 Measures to prevent or minimise the effects of fire

4.3.1 Detection

A fire is always easiest to extinguish in its initial stages. The longer the fire burns, the more heat is transferred to the exposed material in the area, which means more pyrolysis and combustion occurs and that the fire will be more difficult to stop.

Quick fire detection always reduces the time before an automatic extinguishing system can be activated and is therefore equally important as a good fire fighting system. Quick information about the fire also means more time between discovery and the point when the smoke and fire reach the passenger compartment, which creates valuable time for the evacuation of the passengers.

Many conditions which may cause fire can exist long time before the fire starts. Ideally an advanced detection system should be able to detect conditions that could lead to fire, and give the driver the possibility to act to prevent the fire.

4.3.2 Extinguishing system

A tested and classified extinguishing system that is adapted to the bus in question, in combination with good fire detection, is the best first response in the case of an emergency.

A fire fighting system can be activated in two situations i.e.: before the fire to prevent ignition, or during a fire to limit its spread or put it out completely.

If an existing fire is to be extinguished, the extinguishing system must cope with the traffic situation. Different levels of fire fighting capacity are required, depending on whether the fire is being extinguished during driving with a loaded engine, or if the bus is stopped with the engine turned off.

Extinguishing systems should be divided into three classes depending on the following three traffic situations when there is a fire in the vehicle:
1. Vehicle on the road with loaded engine and high ventilation rates in the engine compartment (a difficult case which requires a very high fire fighting capacity).
2. Stationary vehicles with an unloaded engine, an idling engine, and low ventilation rate in the engine compartment (medium difficulty case that requires a high fire fighting capacity)
3. Stationary vehicle with the engine switched off and without ventilation in the engine (relatively simple case that can be accomplished with a lower fire fighting capacity).

The reason the high ventilation rate in the engine makes the fire harder to extinguish is that the extinguishing medium can be transported away giving it less time to work.

Assessment of a fire fighting system will likely be based on the above divisions, the size of the engine, and on fire fighting capabilities and risk of re-ignition. It is important to both manufacturers/sellers that users/purchasers of extinguishing systems to know which of the above traffic situations the system can handle.

4.3.2.1 Measures to improve fire extinguish efficiency
There are measures which positively or negatively affect an extinguishing system's ability to fulfil its task. Here are some actions which have a positive impact on system performance:

1. Automatic shutdown of the engine ventilation at the indication of fire.
2. Lowering of the engine power to reduce the temperature of the exhaust system.
3. If possible, shutting off the engine and breaking the power supply from the battery.
4. Thermal insulation of hot surfaces to prevent re-ignition.

4.4 Conclusions
In order to reduce the number of fires in buses, we have the following recommendations:

1. Separate components to reduce the possibility of producing a dangerous combination of heat, fuel and oxygen.
2. Insulate all hot surfaces in the engine compartment (thermal insulation).
3. Reduce the average temperature in the engine compartment and other vital locations to increase the life of polymer materials.
4. Separate the electrical system into divisible subsystems which can easily, even automatically, be disconnected in case of a fire risk. Keep a basic system of engine and exterior lighting to help safe manoeuvring of the bus until stand-still has been reached. This should not be confused with normal fused circuits.
5. Create new standard for fuses that makes it more difficult to incorrectly mount stronger fuses in the same fuse holders.
6. Minimise mechanical fatigue and other physical effects that can lead to a fire.
7. Ensure quality of service and repairs through staff training, appropriate time allowance, and choosing the correct spare materials. Basic training in fire risks should be included in all training of the engineering staff.
8. Specify (regulate) minimum space in the engine for higher quality of maintenance.

9. Equip the engine compartment with adequate detection system, in combination with a fire fighting system.

10. Educate drivers in fire fighting and fire risks.
5  
Test method for room fire partitions

5.1  
Conditions

The goal is to identify weaknesses in the fire resistance of separating walls between the passenger and engine compartment in particular, but also the wheel houses and surrounding areas. Suggestions for test method(s) for determining the fire resistance and suitable performance requirements are given at the end of the chapter. The project includes testing of different wall constructions to identify the current situation in newer buses.

5.1.1  
What is fire resistance?

Fire resistance of a separating wall is the ability to prevent fire, or other properties that have to do with the fire, from getting through the wall. Fire resistance can be tested in different ways, but the most common way is to expose the samples to a standard time-temperature assault in a test furnace.

Properties of a construction that can be determined through fire resistance testing and may be of interest in connection with buses are:

E  Integrity (tightness)
I  Insulation
K  Fire protective covering
S  Smoke resistance.

5.1.1.1  
E Integrity

Integrity (E) is the ability of an element with a separating function to resist fire on one side without the fire spreading to the unexposed side through leakage of flames or hot gases. When assessing the element's integrity, the following parameters are considered:

- cracks or openings above a certain dimension
- ignition of a cotton ball
- persistent flames on the unexposed side.

5.1.1.2  
I Insulation

Insulation (I) is the ability of an element with fire on one side to maintain the temperature of the unexposed side below a certain level. Generally, the maximum temperature should not rise at any single point to be higher than 180 °C, and the mean temperature rise across the whole sample must not be higher than 140 °C.

5.1.1.3  
K Fire protective covering

Fire protection (K) is the ability of a protective cladding to protect the underlying material against ignition, carbonisation and other damage for a specified period of time.
5.1.1.4 S Smoke resistance

Smoke resistance (S) is the ability of an element to reduce or prevent gas or smoke leakage from one side of the element to the other.

5.2 Why is good fire resistance important?

In case of a bus/coach fire outside the passenger compartment, good fire resistance is one way to guarantee sufficient time for a safe evacuation of the passengers. Sometimes it will also confine the fire damage to the engine compartment.

Fire resistance can be split up in the following modes of action:

1. Extend the time until smoke comes up into the passenger compartment
2. Extend the time until toxic gases appear in the passenger compartment
3. Prevent or make it difficult for the fire to spread from one fire cell to another.

Apart from saving lives and making the evacuation of the passengers easier, proper fire resistance will increase the residual value of the bus/coach after a fire. If the fire can be confined to one fire cell there will be less damage, and less cost to restore the bus/coach to a functional level. The most common bus/coach fires start outside the passenger compartment, especially in the engine compartment. In general, communication between driver and the engine compartment has been very poor. More than 50% of all fires in the engine compartment have been observed by someone other than the driver. Due to a lack of fire detectors (or poorly designed fire detectors) in the engine compartment, the time from the fire start to discovery can be long, sometimes up to about 10 minutes. After the fire has been detected, there must be time for parking, informing and organising the evacuation, and looking after and helping passengers with disabilities, see Figure 1 below.

![Figure 1](image)

### Figure 1

The figure shows the fire resistance from fire start, to fire inside the bus. Note the dependence of a good fire detection compared to the fire resistance.

This means that the earlier a fire is detected the better the change for safe evacuation of the passengers and driver.
5.3 Identification of weaknesses in fire resistance

Normal fires outside the passenger area are primarily engine fires, but there can also be fires in other parts of the bus. Electrical installation appears everywhere in the bus and causes incidents both inside and outside the interior space. The parking heater has historically been a source of fire, but nowadays these are of better quality and such fires are no longer common. Wheel fires may occasionally occur, where the brakes or wheel bearings create friction heat leading to fire.

Fire resistance of separation walls between the engine and bus interior is usually advisable. The problem may be inspection holes with bad seals, connections, for example between the floor and wall, or areas where the thermal insulation is poor. Typically such areas are found in the joints between the various parts and the connectors leading from one fire cell to another.

5.3.1 Material

In general, many good materials are used in today's buses. Common materials used to separate the bus interior from the wheel houses and the engine are plywood and fibreglass reinforced polyester. Fibreglass reinforced polyester has good fire resistance in terms of integrity, but thermal insulation is poor. Thermal/acoustical insulation in the engine compartment usually consists of mineral wool or similar low density material.

5.3.2 Engine – passenger compartment

Most primary fires start in the engine compartment. The danger level is high with many types of fuels in a confined space together with the exhaust system's high temperatures. The most common location of the bus engine is at the back of the bus. Although there are also some buses with the engine located in the middle of the bus, lying centrally in the floor or standing on the side. To achieve a high level of passenger comfort with respect to temperature and noise, there must be thermal and acoustical insulation between the engine and passenger compartments. This insulation can simultaneously provide high fire resistance, provided all surfaces are covered.

5.3.3 Wheel houses – passenger space

Tyre fires occur but this is not a common primary fire. The cause of tyre fire can be an overheated bearing or dragging brakes producing heat. Once the fire is established, it does not take long before it gets outside the wheel houses. Fire resistance in floors, walls and side windows is of high priority. Leaks in the joints between floor and wall and through the side wall can let smoke into the passenger space long before fire breaks out inside the bus.

Sensitive parts are the transition between the wheel house and the side wall because of joints, and the side windows directly above the wheel house. The side walls are usually constructed as a sandwich panel, often with foam as a thermal insulator. Side windows of tempered glass have a relatively short life when flames radiate heat against the pane. Double glazing and a large distance between the wheel houses and side window increases integrity in the case of a fire in the wheel house.
5.4 Safety requirements

Requirements can be set based on life safety and property loss. In the case of evacuation of passengers during a fire the main concern is safety, other factors include facilitation of the evacuation and reducing stress. After a fire, at the residual value assessment, the main concern will always be the cost for the bus restoration and limitations of downtime.

Test evacuations [1] have been conducted with: city, intercity and double-decker buses. A total of 52 healthy people, aged from 17 to 82 years with different levels of fitness, participated in the test. There was a spread of the evacuation times from 28 up to 70 seconds. All three busses were not damaged and standing on the wheels, so the conditions represented a best case scenario. However information from media shows that the evacuation times can be longer.

In the full scale test with a coach conducted as a part of this project, we noted that weak, light smoke got into the bus through the ventilation system and the open middle door. The back part of the passenger space was filled with smoke relatively quickly.

5.4.1 Breakdown of bus bodies into different fire class zones

A possible division into different risk zones would be:

1. Engine compartment
2. Luggage compartment
3. The area around the electric distribution box
4. Wheel houses
5. The remaining spaces under the bus floor
6. Muffler space
7. Space for electrical devices such as fans, batteries, etc.

5.5 Method

Within Europe, fire resistance is tested according to EN 1363-1. In addition to this standard there are some similar standards such as ISO 834. Both use the same load, the so-called ISO curve, where the temperature is regulated by the following equation:

\[ T = 345 \log_{10}(8t + 1) + T_0 \]

\[ T = \text{Furnace temperature in } ^\circ\text{C at time } t \]
\[ t = \text{Time in minutes} \]
\[ T_0 = 20 \text{ degree } ^\circ\text{C (room temperature)} \]

Figure 2 shows the development of the ISO curve as a function of time.
5.6 Testing

During the test, a small furnace with dimensions L x W x H = 1200 x 800 x 1000 mm was used. The test samples were mounted (horizontally) on the furnace top. The height from the top of the stack to the measuring point for furnace pressure (about 100 mm during the test) was 1365 mm, see Figure 5. The opening in the furnace (the exposed surface towards the hot part of the furnace) was 350 x 350 mm. Parameters measured were integrity and insulation. The measurements were carried out according to EN 1363-1, with the following difference to adjust for the smaller size of the furnace:

1. Furnace pressure was measured for the test sample and has been adjusted to level 6 ± 0.5 Pa.
2. Furnace temperature was measured with a plate thermocouple at two points, see Figure 4 and Figure 5.
3. The surface temperature of the test sample was measured at five points, see Figure 3 and Figure 4.

In our tests we chose to measure the surface temperatures of the test samples in a novel manner. A new method was developed for measuring the temperature of flat test samples. The thermocouple is held against the test object's surface with a constant force independent of whether the surface changes position.

All equipment that normally holds a thermocouple against the test sample affects the measurement results in some way (by isolating or leading away heat). In this method an arm keeps the thermocouple in place against the test sample. With this holder, it is only the test sample's surface temperature that affects the thermocouple. This is illustrated in figure 3.
Figure 3. The surface is measured at 5 points with thermocouple against the test plate, a rubber disc, which will be tested. Furnace pressure is measured just below the test sample.

The material of the separation wall between the passengers and the engine area is usually plywood, fibreglass reinforced polyester and metal. These materials can then be covered with PVC matting on the floor and seat chassis, but also textiles such as polyester and other synthetic materials. In the engine area, there is usually acoustical and thermal insulation made of mineral wool and sometimes textile scraps. In sealed connections for electrical cables, rubber materials are often used.

The following materials and material combinations, have been tested according to their fire resistance in terms of integrity and insulation:

1. CR, Chloroprene rubber, 5.5mm
2. NR, Natural rubber, 5.5mm
3. NBR, Nitrile butadiene rubber, 5.5mm
4. EPDM, Ethylene-propylene rubber, 5.5mm
5. AEM, Ethylene acrylic rubber, 5.5mm
6. Rubber joint (from the automotive industry)
7. Acrylic glass 6mm (back window)
8. Fiberglas-reinforced polyester 6mm
9. Plywood 12mm, pine (floor and wall material)
10. Plywood 25mm, pine with PVC coating (flooring)
11. Plywood 25mm, pine with PVC coating and mineral wool insulation 25mm (flooring)
5.6.1 Results from the tests

The fire resistance tests for the rubbers were carried out with rubber plates from Trelleborg – Forsheda Gummifabrik. The thickness of the rubber plates was approximately: 5.5 mm (5.5 mm ± 0.5 mm)

The following rubber qualities were tested:
1. NR, natural rubber number 331
2. CR, chloroprene rubber number 417
3. NBR, Nitrile butadiene rubber number 510
4. EPDM, rubber number 701
5. AEM, acryl ethylene rubber number 3623

The following measured values shall be understood as guideline values from the test results.

Table 7. Fire resistance from five rubber materials

<table>
<thead>
<tr>
<th>Rubber</th>
<th>Burn through time [min:sec]</th>
<th>Burning rate [mm/min]</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR 417</td>
<td>5:30</td>
<td>1,0</td>
<td>It is difficult to ignite the rubber because of its chlorine content.</td>
</tr>
<tr>
<td>NR 331</td>
<td>8:30</td>
<td>0,67</td>
<td>Burns intensively, difficult to extinguish.</td>
</tr>
<tr>
<td>NBR 510</td>
<td>25:00</td>
<td>0,22</td>
<td>Crack formation may shorten the burn through time somewhat.</td>
</tr>
<tr>
<td>EPDM 701</td>
<td>20:00</td>
<td>0,29</td>
<td>Slight expansion in the beginning.</td>
</tr>
<tr>
<td>AEM 3623</td>
<td>11:00</td>
<td>0,5</td>
<td>Crack formation may shorten the burn through time somewhat.</td>
</tr>
</tbody>
</table>

The test results for the fire partition materials are presented below. The table does not contain burn through times as for the rubbers but instead presents an account of the general behaviour for the different materials.
<table>
<thead>
<tr>
<th>Material</th>
<th>Time [min]</th>
<th>Surface temp. [°C]</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber wall entrance (three tests)</td>
<td>3</td>
<td>-</td>
<td>Burn through</td>
</tr>
<tr>
<td>Acrylic plastic</td>
<td>6</td>
<td>-</td>
<td>Burn through (the plastic melted)</td>
</tr>
<tr>
<td>Polyester – fibreglass (three tests)</td>
<td>3-4</td>
<td>120</td>
<td>Thin smoke at the side of the specimen.</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4-5</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>320</td>
<td>The test was finished after 60 minutes. No fire.</td>
</tr>
<tr>
<td>Polyester – fibreglass (three tests)</td>
<td>10</td>
<td>120</td>
<td>Thin smoke</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>160</td>
<td>The surfaces begin to turn darker.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>225 – 300</td>
<td>Small hole at TC 8 – 9</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>225 – 300</td>
<td>Burn through. The first fierce flames.</td>
</tr>
<tr>
<td>Plywood 12mm (three tests)</td>
<td>27</td>
<td>120</td>
<td>This test was ended at 23 minutes.</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>140</td>
<td>Therefore all numbers are estimated.</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>160</td>
<td>Estimated time is included the – tolerance.</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Bus floor without isolation</td>
<td>30</td>
<td>50</td>
<td>Low temperatures after half an hour.</td>
</tr>
<tr>
<td>Plywood 25mm</td>
<td>60</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Bus floor with isolation (25mm)</td>
<td>70</td>
<td>100</td>
<td>The test was ended at 70 minutes.</td>
</tr>
</tbody>
</table>

It is interesting to compare the surface temperature between different materials and material thicknesses. For flooring of 25mm plywood with a mineral wool insulation on the back, it will take considerably longer for pyrolysis gases (smoke) to start spreading compared with the same plywood without insulation. This is a particularly important time when passengers will be evacuated from the fire. In addition, if the structure is smoke resistant, further time could be won.
5.7 Layout for the small furnace

The layout below shows the shape of the small furnace used for our tests.

Figure 4. Top view of the small furnace with location of the thermocouples and the plate thermometers. 1-5 are thermocouples type K, 6 and 7 are plate thermometers, and 8 is the pressure test tube.

Figure 5. Front view of the small furnace with location of the plate thermometers.
The pictures below show the mini furnace, used for our tests.

Figure 6 The mini furnace with the three gas burner.
6 Test method concept for engine compartment fire extinguishment systems

Most bus fires start in the engine compartment. The supply of oxygen, heat and fuel fulfil all the conditions needed for a fire. Very often such fires produce a high heat release rate and therefore cause a lot of damage and spread into the rest of the vehicle. Therefore, these fires should be the primary target for prevention by risk management, design and maintenance. Only secondarily should these fires should be taken care of by an extinguish system.

For environmental reasons one wishes to minimise fuel consumption and therefore the weight of the vehicle. An optimization of the extinguish system is therefore of great importance both in terms of efficiency and weight.

6.1 New test method

There are presently no extinguishing system tests where it is possible to objectively grade the system for different degrees of fire severity. The purpose of this work is therefore to develop a test method where it is possible to test the system performance for different types of fires and other properties influencing the extinguish capacity (e.g. ventilation). Further, risk of re-ignition is also included. The method should be relevant for small engine compartments (1 – 5 m³). When designing this test method the following issues have also been considered: repeatability, reproducibility, and validity.

6.1.1 Conditions in the engine compartment of a bus

Today’s most common engine installation is the rear engine installation with the cooling system at the side of the bus/coach. The engine can be vertical, horizontal or in between. The position can also be oriented along or across the engine compartment. There are different engine fuels. The capacity of the ventilation also fluctuate in the engine compartment depending on the engine load. We have chosen to look at the engine compartment from a strict fire point of view and have tried to imitate the components, properties and events depending on prevailing conditions. Common conditions for all engine compartments are: fuels, temperatures, radiation and ventilation.

The following conditions have been considered specifically:

1. Fuels used in the busses have been employed as possible ignition sources, i.e.: solids: polymers and cellulose and also liquid fuel: hydrocarbon.
2. Typical fires have been simulated, i.e.: flameless combustion (smouldering), flaming fires and spray fires.
3. The location of a fire in the engine compartment
4. The background temperatures in the engine compartment
5. Radiation from warm surfaces (engine body)
6. Radiation from hot surfaces (exhaust system) and the risk of autoignition of different kinds of fuel
7. Varying running conditions and different ventilation levels through the engine compartment.

6.1.1.1 Fuels and fires

Different fuels burn in different ways and it is well known that one specific extinguishing agent or type of extinguishing system is not applicable to all types of fires. Therefore an
extinguishing system must be adapted to the product that may be burning. In light of this a variety of fuels and fires have been tested.

EPDM rubber was chosen to represent the rubber materials. EPDM is a commonly used rubber in engine compartments. Wood pellets were chosen to represent cellulose materials, plywood, and textile products for example acoustic absorbents. Wood pellets were chosen as they are well specified and exhibit glowing behaviour when burning. This types of fuels represents the fibrous fires.

Diesel oil was chosen to represent thermoplastics as these burn in similar way to oil fuels. Similary, liquid fuels such as diesel oil and engine lubricating oil were represented by diesel oil. Finally gaseous fuels such as LPG and CNG are easily mixed with air and burning intensively. The same is true for an aerosol of, for example, diesel oil. Thus a burning spray of diesel fuel was used to simulate such fires.

Table 9 contains a summary of different types of fuel (e.g. fibrous, liquid or gaseous), examples of fuels that exhibit behaviour typical of this type of fire and a description of the characteristics which typify each type.

<table>
<thead>
<tr>
<th>Type</th>
<th>Type of fuel</th>
<th>Example of fuels</th>
<th>Character of the fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Fibrous fuels</td>
<td>Wood, coal and &quot;rubber&quot;.</td>
<td>Smouldering and glowing</td>
</tr>
<tr>
<td>B</td>
<td>Liquid state of fuels</td>
<td>Diesel, plastic och solvents.</td>
<td>Calm flames</td>
</tr>
<tr>
<td>C</td>
<td>Gaseous fuels</td>
<td>LPG, CNG and diesel fog</td>
<td>Intensive flames (spray fire)</td>
</tr>
</tbody>
</table>

Fires in engine compartments can fall into all three types of fuels. The most common fires are of B-type with liquid fuels. Engine and diesel oil are frequently present under pressure and a leakage will therefore often result in a spray fire. Smouldering fires, type A, are more prevalent in the later stages of the fire.

6.1.1.2 Location of the fire sources
One of the biggest challenges when installing an extinguish system in an engine compartment is the location of the nozzles. Sometimes the engine compartments are so compact that installation is very difficult.

An installation in a real engine compartment always begins with a risk analysis. Thereafter, pipes and nozzles are distributed. In a narrow engine compartment, it can sometimes be difficult to cover all spaces, which means that the fire may be difficult to extinguish. Airflow through the engine compartment is a determining factor and can sometimes prevent the extinguish agent to reach the fire. High air flows can reduce the capabilities of the extinguishing system to a fraction of full capacity.

Three of the five fire sources in the test chamber are located more or less hidden and are therefore a challenge to extinguish.

6.1.1.3 Temperatures and radiation in the engine compartment
The engine and the exhaust system emit heat to other parts in the engine compartment and therefore create a favourable climate for fires. The heat is transmitted by contact, convection and radiation. In the engine compartment this will happen by direct contact between details assembled close to each other (contact), the ventilation air passing the engine and the cooling system (convection) and finally the radiation from the engine body and the hot surfaces in the exhaust system. Temperatures up to 90 – 100 °C in the engine compartment are not unusual. This is above the flashpoint for CNG, LPG, ethanol and diesel oil. The flashpoint of the engine lubricating oil ranges from 170 – 220 °C.
The surface area of an engine in a bus/coach is roughly between 3 – 4 m². Normally 75% of this surface is exposed to the engine compartment. The temperature fluctuates slightly across the engine body surface, but will stay in the range of 80 – 100 °C. The mass of the engine body is high and the temperature will therefore equilibrate within 5 – 10 minutes.

The hot surface area of the exhaust system (exhaust pipe and turbo) is about 0.3 – 0.5 m² and the temperature is 350 – 600 °C. The thickness of material in the exhaust pipe is between 4 – 5 mm. The thickness of the turbo material varies but on average 8 – 10 mm can be typical for the hot surfaces. Remaining parts of the exhaust system have normally thinner walls and lower temperatures.

The walls of the engine compartment are lined by acoustical panels. These panels also provide good thermal insulation, which may increase the temperature to 80 – 100 °C in the engine compartment.

6.1.1.4 Running conditions in the engine compartment
The ventilation in the engine compartment is normally high when the engine is running. Even the dynamic pressure, when the bus/coach is running, influences the ventilation rate because of pressure differences. The extinguishing system should work under the following three conditions:

1. The bus/coach is running, the engine is loaded and the engine speed is working at the maximum torque (~ 1300 v/min).
2. The bus/coach is parked and the engine is idling.
3. The bus/coach is parked and the engine is shut off.

Other conditions which should be controlled for each of the three cases in the engine compartment are described in the table below

<table>
<thead>
<tr>
<th>Engine state</th>
<th>Ventilation</th>
<th>Exhaust system</th>
<th>Engine body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loaded</td>
<td>High</td>
<td>600 °C</td>
<td>95 – 100 °C</td>
</tr>
<tr>
<td>Idling</td>
<td>Low</td>
<td>600 °C</td>
<td>~ 90 °C</td>
</tr>
<tr>
<td>At shut off</td>
<td>Very poor</td>
<td>500 and decreasing</td>
<td>~ 90 °C Slowly decreasing</td>
</tr>
</tbody>
</table>

6.1.1.5 Air flow
All information concerning air flow through the cooling package is given by the Swedish bus manufacturers. The air flow through the engine compartment is approximately 30 – 40 % of the full capacity through the cooling package (fan and heat exchanger) because of the confined space available in the engine compartment due to sound proofing.

In the table below we have summarised the average values from the air flows through the cooling package.

<table>
<thead>
<tr>
<th>Engine speed</th>
<th>0 rpm (m³/s)</th>
<th>500 rpm (m³/s)</th>
<th>1300 rpm (m³/s)</th>
<th>1700 rpm (m³/s)</th>
<th>2200 rpm (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air flow (average)</td>
<td>0</td>
<td>1,5</td>
<td>3,7</td>
<td>4,7</td>
<td>5,9</td>
</tr>
</tbody>
</table>

Today there is a trend that the cooling system is moving up onto the roof, especially for city buses. This is to protect this package from dirt coming up from the rear wheels.
When the weather is unfavourable the cooling systems sometimes has to be cleaned once a week when located under the bus. This is also a quality problem because the cooling capacity can be decreased below the minimum limit. The consequences of such a decrease are too high temperatures in the engine and engine compartment.

### 6.2 Design of the test chamber

The aim has been to produce a test method, for water based extinguish system, mimicking the conditions in a rear engine compartment in a bus/coach. The test chamber has the same generic structure as the engine compartment in a city bus with a rear engine. The characteristics of all parts and fire sources are strictly defined to ensure experimental repeatability and reproducability. This also means that comparative assessments of extinguish systems can be conducted, even after a few years.

The test chamber was designed in a reduced scale, 1/3 of a normal engine compartment of a city bus, to make the test method easily manageable on a laboratory scale. This results in same temperatures as for the full size situation, but with dimensions for the experimental components, and output and amount of fuels reduced to 1/3 of the full size.

The test chamber has following specification:

1. The design of the test chamber corresponds to a rear engine compartment in a normal city bus.
2. The volume of the test chamber is about 1.2 m³ and is possible to expand up to 150 %. The air temperatures is kept between 70 and 90 °C.
3. The surface area of the engine mock-up, including the cavity, is 0.99 m². The mock-up is heated by water from the inside and the temperature is kept to 90 – 95 °C.
4. The surface of the exhaust pipe and turbo mock-up is 0.135 m² and the thickness of material is 4 mm and 8 mm respectively to correspond to the exhaust manifold and the turbo.
5. When heating the exhaust pipe mock-up all the rest of the testing chamber achieves a steady temperature corresponding to a normal engine compartment.
6. Only 1/3 of the nozzles and the extinguish agent in the system take part in the test.

In the evaluation of an extinguish system there must be a number of different criteria to ensure a correct assessment of the system for every running condition. In this context the following conditions must be noted:

1. Extinguishing performance with different locations of the fire sources.
2. Type of fuel used, e.g. combustible fluids in mineral wool, an aerosol (spray) or wood pellets and rubber pieces for a smouldering fire.
3. Re-ignition behaviour.
4. Vehicle operating conditions as defined in section 6.1.1.4.

Variable conditions in the test method:

1. The air flow through the test chamber and the air temperature.
2. The volume of the test chamber.
3. The temperature of the engine body and exhaust pipe.
4. The heat release of the fire sources.
5. The location of some fire sources.
6. The type of fuel used in the fire sources.
6.2.1 Description of the layout of test rig

The sketch below shows the principle structure of the test rig, the function and location of the details included in the rig. An explanation of the numbers in the figure is provided in the Figure Legend.

**Top view**

**Side view**

**Figure 7. An explanatory sketch over the test rig**

**Figure Legend:**
1. Spray fire (*diesel*)
2. Engine fire, location in a cavity in the engine mock-up (*diesel in mineral wool*)
3. Rear wall fire (*diesel in mineral wool*)
4. Pool fire (*diesel in mineral wool*)
5. Smouldering fire (*rubber*)
6. Smouldering fire (*cellulose*)
7. The exhaust pipe mock-up
8. The exhaust pipe heater (*5 propane burners*)
9. The engine mock-up, with a cavity for the engine fire.
10. Air inlet
11. Air outlet
6.2.2 Airflow through the test chamber

The airflow through the test chamber is produced by an axial fan. After the axial fan there is a small space with baffles to focus the air flow towards the centre. Before entering the test chamber, there is a flow resistance making the air flow more homogeneous. The cross-sectional area of the opening is ~ 0.3 m², see Figure 8.

Based on the air flows given in section 6.1.1.5 the following is assumed:

1. ~ 35% of the total air flow through the cooling system passes the engine compartment.
2. When the engine is loaded we assume the engine speed to be at the maximum torque ~ 1300 r/m.
3. The idling speed is 500 r/m.
4. When the engine is shut off, the oxygen supply to the engine fire will be very poor. Therefore we assume that the engine fire has started when the engine was running and that the engine is shut off at the same time as the extinguish system is activated. This is simulated with a very low air flow through the test chamber.

The airflow flows are then converted into air speeds in the test chamber. The air speed through the test chamber is measured in the middle of the air outlet. This cross-sectional area of this opening is ~ 0.3 m² (0.375 x 0.8 m) and the measurement is taken in the centre of the opening and 10 cm below the level of the opening.

<table>
<thead>
<tr>
<th>Engine speed (rpm)</th>
<th>0</th>
<th>500</th>
<th>1300</th>
<th>1700</th>
<th>2200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow through the engine cooling system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% flow (m³/s)</td>
<td>0</td>
<td>1.5</td>
<td>3.7</td>
<td>4.7</td>
<td>5.9</td>
</tr>
<tr>
<td>35% of the total flow (m³/s)</td>
<td>0</td>
<td>0.45</td>
<td>1.3</td>
<td>1.65</td>
<td>2.07</td>
</tr>
<tr>
<td>Airspeed through the outlet hole (0.3 m²) (m/s)</td>
<td>1.1*</td>
<td>1.5</td>
<td>4.33</td>
<td>5.5</td>
<td>6.9</td>
</tr>
</tbody>
</table>

*There must be a minimum of oxygen in the test chamber for supplying the fire sources.
6.2.3 The fire sources

There are six fire sources in the extinguishing equipment test method, five inside the test chamber and one just below the air outlet.

The fire-source in the test chamber consists of:

1. One spray fire (diesel fuel)
2. Two smouldering and glowing fires (granulated rubber /EPDM/ and pellets /cellulose/)
3. Three fuel fires (diesel fuel)

Location of the fire sources is shown in Figure 7.

6.2.3.1 The spray fire system

![Figure 9. An explanatory sketch for the spray fire.]

The spray fire system consists of three parts:

1. The nozzle (full cone, 60 °, X gram/min/10 bar).
2. A flame defence (see Figure 9)
3. A flame stabiliser (a hot steel net to accelerate the evaporation)

![Figure 10. The spray fire burner.](image)
6.2.3.2 The smouldering/glowing fire system
The smouldering/glowing fires are located in a net basket made of stainless steel. There is a partition wall in the basket giving two compartments, one for each fuel. The basket is shown in Figure 11 and the two fuels are shown in Figure 12 and Figure 13.

1. Smouldering fire (rubber)
2. Glowing fire (cellulose)

Rubber and cellulose
The rubber fuel was an EPDM rubber, 50 Sh (shore), an extruded profile with the thickness of 5 mm. The profile was then cut in pieces of about 5 mm length. Fire performance of the rubber granulate is shown in Figure 14.

Figure 11. The net basket

5 mm

Figure 12. The rubber profile

Figure 13. The smouldering rubber fire load in the net basket compartment No 1.

The wood pellets in the net basket compartment No 2.
Cellulose
The cellulose fuel was of the type wood pellets. A specification of the fuel is given in Table 13. The fire performance of the wood pellets is shown in Figure 16.

Table 13. Specification of the wood pellets

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy / kg</td>
<td>~ 4,8 kWh</td>
</tr>
<tr>
<td>Energy / m³</td>
<td>~ 3120 kWh</td>
</tr>
<tr>
<td>Volumetric weight</td>
<td>~ 650 kg/m³</td>
</tr>
<tr>
<td>Diameter of the pellet</td>
<td>8 mm</td>
</tr>
<tr>
<td>0,5 litre wood pellets</td>
<td>Measured mass: 314 g</td>
</tr>
</tbody>
</table>

Figure 14. Rubber granulate 0.03 m². The HRR reached 5 kW after 3 minutes. Ignition at 01:00 minutes.

Figure 15. The wood pellets with a diameter of 8 mm

Figure 16. Wood pellets 0.05 m². The HRR reached 5 kW after 3 minutes. Ignition at 00:45 minutes.
6.2.3.3 The three “liquid fuel” fires

Each of the fuel fires (the “engine fire”, the “rear wall fire” and the “pool fire”) consisted of a steel pan filled up with mineral wool with a density of 150 kg/m² (Isover fire protect 150). The mineral wool was then soaked with sufficient diesel oil in the pan to form a pool of diesel oil when you press a finger against the mineral wool surface. On top of the pan the exposed surface area of the mineral wool – diesel oil combination is variable using covers. The recommended pre-burn time is 1 minute.

![Figure 17. The pan of the rear wall and pool fire. The burning surface area is adjustable using two covers.](image)

The dimensions of the pans were:

1. Rear wall and pool: L x B x H = 0.6 x 0.2 x 0.05 m, surface area: 0.12 m²
2. Engine cavity: L x B x H = 0.35 x 0.2 x 0.05 m, surface area: 0.07 m²

The maximum heat release from the rear wall and pool fire is approximately 150 kW. Results from tests with diesel oil in mineral wool (Tests No 1 and 2) were used to calculate the heat release rate from weight loss, while Tests No. 3 and 4 were carried out according to EN13823 and oxygen consumption measuring calorimetry was used to determine the heat release rate, see Table 14.
Table 14. Calculated power from weight reduction/unit of time

<table>
<thead>
<tr>
<th>No</th>
<th>Surface</th>
<th>weight reduction average (g/s)</th>
<th>Diesel 39.7 MJ/kg</th>
<th>HRR (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 x 60 cm</td>
<td>96</td>
<td>39.7 x 10^3 x 96/60</td>
<td>63.5</td>
</tr>
<tr>
<td>2</td>
<td>20 x 35 cm</td>
<td>44</td>
<td>39.7 x 10^3 x 44/60</td>
<td>29.1*</td>
</tr>
</tbody>
</table>

Tests in SBI

<table>
<thead>
<tr>
<th>No</th>
<th>Surface</th>
<th>Diagram No z</th>
<th>HRR (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>20 x 20.5 cm</td>
<td>~ 20</td>
<td>~ 20</td>
</tr>
<tr>
<td>4</td>
<td>20 x 40 cm</td>
<td>~ 40</td>
<td>~ 40</td>
</tr>
</tbody>
</table>

* This test result, from the engine cavity, is lower because of the three walls around the fire.

Figure 19. Diesel soaked up in mineral wool. From 0 – 5 minutes the surface was: 0.012 m². After fully 5 minutes the surface was doubled. Igniting at 01:00 minutes.

6.2.4 Temperature measurement in the test chamber

The temperatures in the test chamber are measured using thermocouples (TC).

There are two categories of thermocouples:
- Category I for indicating correct initial conditions before staring the tests, i.e., TC 1 – 8.
- Category II for indicating when the separate fires are extinguished, i.e., TC 7 -16, with TC 7 and 8 specifically used for the spray fire.

A full list of TC 1-16:

TC 1 – 3 The exhaust pipe
TC 4 Water temperature in the engine mock-up
TC 5 – 8 Air temperatures (TC 7 – 8: spray fire)
TC 9 – 10 The engine fire
TC 11 – 12 The rear wall fire
TC 13 – 14 The pool fire
TC 15 – 16 The smouldering fire

Figure 20 shows the placement of the various TCs.
Figure 20. Locations of the thermocouples (TC) in the test rig.

**Figure Legend:**
- TC 1 – 3: The exhaust pipe
- TC 4: Water temperature in the engine mock-up
- TC 5 – 8: Air temperatures (TC 7 – 8: spray fire)
- TC 9 – 10: The engine fire
- TC 11 – 12: The rear wall fire
- TC 13 – 14: The pool fire
- TC 15 – 16: The smouldering fire

Figures 21 - 22 show the test rig and engine dummy.
Figure 21. The test chamber including surrounding equipment.

Figure 22. The engine dummy with the cavity for the diesel fire.
6.3 The test procedure

The test procedure is divided in four steps.

1. **Preparation**: Study the test rig, assemble the extinguish system, test the spray pattern from each nozzle, calibration of the capacity, calibration of liquid flow through 1/3 of the nozzles (1/3 of the total capacity of the extinguish system).

2. **Start-up**: Start up the measuring system. A couple of minutes before activating the exhaust system: heat the engine mock-up to the correct temperature (90 – 95 °C), heat the exhaust pipe mock-up to the correct temperature (500 – 600 °C), ignite all fires in the test chamber, and let them burn for the specified pre-burn period.

3. **The test**: Activate the extinguishing system. Read the data from TC 7 – 16, as a first indication of extinguishing succession. Wait for some minutes before opening the door to the test chamber.

4. **The results**: The final judgement of the capacity of the extinguish system will be described as:
   1: Classification A, B or C, depending on test procedure.
   2: The ability to extinguish the six fire sources. If Extinguishment does not occur note the remaining fires.

**Customizing of the extinguishing system to fit the test chamber.**

The volume of the test chamber is about one third of the real engine compartment of a city bus. Therefore the number of spray nozzles and extinguishing medium in the test must be a maximum of 1/3 of the real system.

Figures 23 - 27 shows different parts of the test procedure.

---

Figure 23.
Calibration of the capacity for 1/3 of the system.
Figure 24. Testing the spray distribution from two nozzles in the test chamber.

Figure 25. Pre-heating of the exhaust pipe mock-up to 600 ºC.

Baffle plate to protect the spray fire burner during the pre-heating of the exhaust pipe.

The engine mock-up is heated with hot water to 95 ºC.
Figure 26. Pre-burning time for the fire source: 1 - 2 minutes before the tests.

Figure 27. The extinguishing system is activated.
6.3.1 The test set-up

The test program:

<table>
<thead>
<tr>
<th>Classification</th>
<th>[Air speed]</th>
<th>Description</th>
<th>Spray fire</th>
<th>3 diesel fires</th>
<th>Smouldering fires</th>
<th>Temperatures [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[1,1 m/s]</td>
<td>Engine stopped (parked)</td>
<td>No [2]</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>[1,5 m/s]</td>
<td>Parked with engine running</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>A</td>
<td>[4,33 m/s]</td>
<td>Bus on plane road, full with passenger</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

1. The air flow is measured in the centre of the air outlet in the floor.
2. There are no pressure in the liquid systems when the engine is stopped.

6.3.1.1 Preparation

1. Calibration of the air flow, through the test chamber.
The air flow will be measured in the test rig just above the grating of the outlet opening. The uncertainty must be within +/- 0.1 m/s.

2. Calibration of the liquid flow through 1/3 of the nozzles
The extinguish liquid used during the test must be a maximum of 1/3 of the full scale amount. During the test all nozzles must be connected to the system, but just 1/3 of the nozzles installed in the test chamber. The other nozzles, or one nozzle with the same capacity as the 2/3 together, must be connected to a separate waste tank.

3. Pre-heating of engine.
The temperature of the engine must be minimum 95 °C before the test for all tests except for the spray fire. The engine is heated with hot water.

4. Pre-heating of exhaust pipe.
The mean temperature of the exhaust pipe must be minimum 600 °C before all the tests.

1. Calibration of the air flow. Measure the air speed inside the rig just below the outlet hole.
3. Engine fire: ………………………………… Preheating: minimum 1 minute.
4. Rear wall fire: ………………………………. Preheating: minimum 1 minute.
5. Pool fire: …………………………………… Preheating: minimum 1 minute.
6.3.2 Layout for a test protocol

Order number: ………                      Test Nr:      ,  200X – –

Year – month – day

Extinguishing system: _________________________________________________
Extinguishing liquid: _________________________________________________
Type of nozzle: _____________________________________________________
Number of nozzles: ___________________________________________________
Position: ___________________________________________________________
Direction: __________________________________________________________

Container
Weight before test: ___________________________________________________
Weight after test: ___________________________________________________
Net: _______________________________________________________________
Working pressure: ___________________________________________________

Exhaust pipe temp.: 600 °C ___, 500 °C ___

Configuration:

<table>
<thead>
<tr>
<th>Air speed</th>
<th>Spray fire</th>
<th>Engine fire</th>
<th>Rear wall fire</th>
<th>Pool fire</th>
<th>Door</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. (4,3 m/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. (1,5 m/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. (1,1 m/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Type of fuel: _________________________________________________________

Special for this test: _______________________________________________

Result: Extinction: No extinction:

<table>
<thead>
<tr>
<th>Time (min:sec)</th>
<th>Event</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>Start measuring</td>
<td></td>
</tr>
<tr>
<td>01:00</td>
<td>Start heating the exhaust pipe</td>
<td>Igniting the propane burners</td>
</tr>
</tbody>
</table>

Signature: _______________________________________________________

Place  Date   Technical officer
6.3.3 Experience from tests conducted within this project

We have performed a large number of tests with two different water spray systems as a part of this project. This section contains our experience from these tests. The difference between the two systems mainly concerned the droplet size distribution. Both systems are water mist systems since typical droplet diameter is <1 mm. Our experience from these tests is as follows:

1. Different droplet size distributions give different extinguishing properties.
2. Small droplets are easily vaporized and gives a high fire extinguishing capacity for large fire sources, but they are sensitive to ventilation since the air flow may remove the mist from the fire. Further they do not perform as well with glowing fires since the mist does not penetrate the fire well.
3. Large droplets evaporate more slowly and a direct hit on the fire is required for good extinguishing performance. However, large droplets penetrate well in glowing fires and are efficient at cooling hot objects.
4. In order to obtain an optimal extinction capacity with a water spray system it would be beneficial if the drop size distribution could be varied during the time for extinction.
5. It would also be good to adjust the droplet size distribution for different fire sources to minimize the risk for re-ignition.

In the test rig the engine fuel fire is a challenge due to the high mass of the hot engine mock-up and due to the down-stream position of the fire.

The final judgment of a fire extinguishing system can be described as follows:
- A classification into one of the classes A, B and C (corresponding to the three different driving conditions, see section 6.3.1), where the results from all tests (spray fire, smouldering fire, fuel fires in engine, rear wall, and in pool) should pass the requirements within each level (A, B, and C).
- Alternatively each driving condition can be mentioned for each test.

Preparations

Experience from the tests performed as part of this project clearly showed that preparations before a test are an important part of the test. It is important do understand what conditions prevail in the test rig in order to position the nozzles in an optimized way. The position of the fire sources as well as characterization of the sprays with and without air flow are important data. This information is also important when an extinguishing system is adjusted for a specific engine compartment. It is also important to understand the effect of ventilation and where fires are expected to occur. The system should also be configured in such a way that re-ignition is avoided. When all assembling, adjustments and calibrations are done, the testing can start.

The test

In all test situations good repeatability and reproducibility is important. This means that all adjustments of parameters, such as fire sources and air flows for example, need to be the same for all tests. In particular the following issues should be given careful attention when running a test:

1. Heating of the engine mock-up and exhaust pipes takes time and needs to be started well before the test.
2. The pre-combustion times for the different fire sources need to be correct in order to obtain the same representative heat release rate in different tests.
6.4 Conclusions

The aim of this work has been to develop a method which represents all the characteristics of a real engine compartment and mimicks the same conditions with respect to the fire. The method is intended primarily for testing water-based extinguishing systems, but can also be used for other extinguishing agents. The major advantages of this method are:

1. It is a model of an engine compartment in a bus, but can also be used for other types of vehicles.
2. The method contains all the conditions prevalent in a real engine compartment, with respect to: temperatures, radiation, fuel and air flow.
3. The test is divided into different difficulty levels corresponding the driving cases:
   A. The bus on the road with loaded engine,  B. The bus parked with the engine idling, and C. The bus parked with the engine switched off.
4. Fire sources, temperatures and air flows can be specified which facilitates repeatability of the tests and reproduction of the system assessed in a real application.
5. These conditions meet the requirements for international testing.

We believe there is a need for a method where it is possible to assess the capacity of the fire protection in different steps. The test should be such that it resembles real scenarios. This would help producers to quickly and relatively cheaply test their products in the developmental stages of product design and determine when further development is needed or when a prototype is ready for the market. When the finished product is released sellers and buyers will have a common understanding of the system performance to facilitate their discussion of how the system should be used and what acceptance criteria are relevant.

A substantial amount of work is required before a standard can be formulated. The method is not yet complete although a prototype test method exists. Test series under different conditions and validation in real bus engine compartments is needed in order to enable the use of test results in assessing the full performance of a fire extinguishing system.
7 Bus fire simulation

In this chapter it is shown how Computational Fluid Dynamics (CFD) simulations can be used to estimate how the environment in a bus will develop when subject to fire. These simulations are particularly suited for estimating the movement of smoke and heat inside the bus. Some conclusions and recommendations are given at the end of the chapter but the main purpose here is to generally illustrate how these types of simulations can be applied to buses.

7.1 Scenarios simulated

The following fire scenarios have been simulated:

- Spread of heat and smoke from a burning seat in the rear end of the bus. Fire spread to other parts of the bus was included in the model. The following configurations were compared:
  - Open and closed roof hatches (open doors)
  - Open and closed doors (closed roof hatches)

- Spread of heat and smoke from a burning seat in the rear end of the bus. In addition spread of the fire inside the bus was included in the model.

7.2 CFD using Fire Dynamics Simulator (FDS4)

CFD models are so called field models which means that the solution to a problem is computed on a numerical grid. The grid consists of grid cells and the solution is calculated for each grid cell in the investigated volume. What is referred to as the “problem” above is the system of conservation equations of mass, energy, and momentum together with initial and boundary conditions such as initial fire, material parameters, wind conditions and so on. A large number of commercial and research CFD codes are available on the market. In this project the research code “Fire Dynamics Simulator, version 4” (FDS4) was used.

7.2.1 Transport of smoke and fire gases

FDS4 is applicable to low-speed, thermally-driven flow and the emphasis is on simulating transport of smoke and heat from fires [2]. The quantity of smoke produced is determined by material parameters which in general are less well known. In other words: FDS4 is good at simulating movement of smoke but less good at predicting the amount of smoke that will be generated in any given fire.

7.2.2 Smoke production

An important result from the simulations is the visibility. This is a measure of how far it is possible to see through the fire smoke. Visibility decreases when there are soot particles in the fire smoke. The production of particulate smoke in the fire is defined by the parameter SOOT_YIELD. This parameter specifies the mass yield of soot, that is, the mass of produced soot per mass of consumed fuel. In this work the soot yield was set to 0.19 g/g. This is the average value for four flexible polyurethane foams tabulated in Table 3-4.14 in Tewarsson [3]. It is a rather high yield compared to most other combustibles but still the best available value for the seat used as ignition source in this model, see below.
7.2.3 Fire source

There are two ways of designating a fire in FDS4. These are:

1. prescribe a heat release rate per unit area of the fire, or
2. prescribe a heat of vaporization and heat of combustion for the combusted material.

Using the method with heat of vaporization is inherently difficult since the burning rate in this case will depend on the radiation feedback from the combustion in gas phase to the surface, and also depends on the heat transfer in the combusted material. These effects are generally not well known and therefore lead to large uncertainties in the calculated heat release rate. Consequently the method of prescribing a heat release rate per unit area has been used in this work. This method on the other hand requires a priori knowledge of how fast the modelled materials are combusted. Luckily this information is available for a number of materials from Johansson and Axelsson [4]. Examples of such curves describing the heat release per unit area as a function of time are given in section 7.3.3.2 below.

In FDS4 only one type of fuel can participate in the fire. Flexible polyurethane foams (PUR) is a very common form of upholstery in vehicle seats and it is therefore reasonable to assume that this is the material being combusted in the fire. The unit composition of polyurethane is C_{6.3}H_{7.1}NO_{2.1} and its molecular weight is 130.3 g/mole [5,6]. This data is needed in the model in order to relate the released heat to the smoke produced. By default it is assumed that 13.1 MJ heat is released per kg of oxygen consumed [2].

7.2.4 Model uncertainty

CFD calculation of smoke and fire spread are inherently sensitive to numerical as well as physical parameters. The most important numerical parameter is the size of the grid cell. The grid cell is the smallest single volume where the solution to the problem is calculated. In order to obtain a numerical solution that is a good approximation to the analytical solution of the problem the size of the grid cell must not be too large. A large grid cell means that the total number of grid cells decreases and therefore the computation time also decreases. However, too large grid cells mean that the numerical solution becomes a poor approximation of the analytical solution. It is also possible that the computations do not converge to a solution, meaning that no result is obtained. The grid used in the calculations is discussed in section 7.3.1 while the sensitivity of the calculations in the grid cell size is investigated in section 7.4.4.

7.3 Input to the model

The bus is shown in Figure 28 below. The interior dimensions of the bus are 12.37 m length, 2.24 m width, and 2.07 m height.
Figure 28. The bus. The roof has been cut out from the image in order to show the seat configuration inside the bus. The seat used as ignition source is shown in red at the rear end of the bus. The small yellow cubes that are found at various places inside the bus are measurement points where parameters such as visibility and temperature, for example, are recorded as a function of time.

7.3.1 Grid and grid stretching

As mentioned above the size of the grid cells is important for the quality of the solution from the simulation. The grid in one plane is shown in Figure 29 below. Not only the bus is included in the computational volume but also the space nearest the openings of the bus. Although the main interest is what happens inside the bus it is necessary to have a computational volume outside the bus in order to correctly simulate the ventilation of the fire. The size of the grid cells is also illustrated for an arbitrary selected plane. The size of the grid cells is smaller inside the bus than outside. The reason for this is that it is necessary to resolve the combustion inside the bus as well as possible. A good resolution of the fire is obtained with a small grid cell size. Outside the bus there is no combustion but only transport of gases. Therefore the size of the grid cells can be larger outside the bus. This method of differentiating the size of the grid cells is called grid stretching. It is a powerful method for using the computational time as effectively as possible. The size of the grid cells inside the bus is 5 cm except for one simulations shown in Figure 44.
7.3.2 Initial fire

The initial fire is supposed to simulate an arson event close to the back seat. The prescribed HRR was taken from the heat release as a function of time that was measured during a test on a single seat with Trevira CS textile on PUR-foam upholstery. The complete seat was exposed for 2 minutes to a propane ring burner with a heat output of 30 kW, see Figure 30 below. Details for the test are given in Johansson and Axelsson [4].

The resulting heat release curve is given in Figure 31 below.
Figure 31. Heat release rate as function of time for the seat used as initial fire.

It is not practical to specify the heat release rate with such a high temporal resolution as in Figure 31 above. Rather, a ramp function that roughly replicates the measurement data is good enough for this application. The ramp used in this work is given in Figure 32 below, together with the original measurement data.

Finally, in the implementation in FDS4 it is the heat release per unit area, HRRPUA, that is prescribed as a function of time. Therefore the heat release in the ramp function needs to be divided by the burning surface. It is assumed that it is the upper part of the seat cushion and the front of the backrest that are the main contributors in the fire. This is also confirmed when video uptakes of the test are studied. The area of the upper side of the
seat cushion is 400 mm x 450 mm = 0.18 m² while the area of the front side of the backrest is 400 mm x 600 mm = 0.24 m², giving a total combusting area of 0.42 m². The maximum heat release rate in the ramp function is 240 kW. This gives a HRRPUA of 240/0.42 = 571 kW/m². This maximum HRRPUA together with a normalized ramp function is given as input to FDS4.

The ignited seat is assumed to be positioned in the left row in the rear of the bus, see Figure 33 below.

![Figure 33](image)

**Figure 33. Illustration of the burning seat used as initial fire. Although the entire seat is red it is only the upper side of the seat cushion and the front side of the backrest that participate in the fire.**

### 7.3.3 Material properties

Material properties are important mainly when flame spread is included in the model. It is then necessary to prescribe parameters such as ignition temperature, thermal conductivity, specific heat capacity, density, and heat release rate per unit area, HRRPUA, for the materials included.

#### 7.3.3.1 Seats

The heat release rate for burning seats is described by the ramp function shown in Figure 33 above. However, for flame spread calculations it is also necessary to know the

---

3 The maximum value of the HRRPUA ramp is 508 kW/m² instead of 571 kW/m² which is the value used when a single seat is the initial fire. The reason for this is that when a single seat is used as the initial fire it is assumed that the top of the seat and the front of the backrest are on fire. The area of these two surfaces is 0.42 m². However, when the double seats is used as ignitable fuel in
thermal properties and the ignition temperature of the seat surface. Thermal and ignition data for materials similar to bus seats have been taken from Chen [7]. In this study it was found that treating fabric-foam upholstered furniture as thermally thin [8] gives more reliable results than if they are treated as thermally thick. A thermally thin material is defined by the lumped parameter $C \delta \rho$ in FDS4. This is the product of the specific heat, $C$, the thickness of the material, $\delta$, and the density, $\rho$. In Chen [7] it was found that the average $C \delta \rho$ for 14 fabrics was 1.30 kWm$^{-2}$K$^{-1}$ while the average ignition temperature was 280 ºC. These parameters are used in the FDS4 model in this project.

The experimentally determined material properties mentioned above are considered to be the best available data. Therefore these values are used in the model instead of thermal data applicable for materials such as PUR or the Trevira textile (Trevira is a trade name for polyethylene terephthalate, PET, or polyester). The reason why the experimental data from [7] are considered to be the best available data for this study is that they apply to actual composite furniture, such as a bus seat, while tabulated data for PUR and PET are only applicable to pure substances.

7.3.3.2 Walls and ceiling

The walls are assumed to be clad with needle felt, an example of which is shown in Figure 34.

Figure 34   Needle felt

Needle felt is typically made of PET (polyethylene terephthalate, also known as polyester) [9]. When the needle felt is exposed to heat it rapidly melts. This means that in a fire scenario the needle felt mainly contributes in molten form, that is, in the form of bulk PET. Material properties for bulk PET have been obtained in two ways; i.e. from standard tabulated material data [10] and using Janssens’ procedure for estimating ignition temperature and thermal inertia [11].

flame spread calculations it is assumed that the surfaces facing the gangway are also ignitable. The surface facing the gangway is 0.045 m$^2$ for the seat and 0.06 m$^2$ for the backrest. Since the max heat release of one single seat is 240 kW the corresponding max HRRPUA for the ignitable double seat is $2 \times 240 / (2 \times 0.42 + 0.045 + 0.06) = 508$ kW/m$^2$. 

The company Goodfellow offers easily accessible material data on their website. For PET the following properties are given [10]:

- Thermal conductivity $K$: 0.15-0.4 Wm$^{-1}$K$^{-1}$ (at 23°C)
- Density $\rho$: 1300-1400 kgm$^{-3}$
- Specific heat $C$: 1200-1350 JK$^{-1}$kg$^{-1}$

One common method in fire technology for determining thermal inertia and ignition temperature is to irradiate the material at different irradiation levels and measure the time to ignition. There exist several models for how thermal inertia and ignition temperature can be extracted from the test data. In this work the method of Janssens’, assuming a thermally thick material, has been used [11]. Details of the investigation are given in Appendix 1. The results are summarized below:

- Thermal inertia $K\rho C$: $7.04 \cdot 10^5$ J$^2$m$^{-4}$s$^{-1}$K$^{-2}$
- Ignition temperature: 257°C

FDS4 requires not the bulk property $K\rho C$, but the individual factors $K$, $\rho$, and $C$. The thermal inertia $K\rho C$ $7.04 \cdot 10^5$ J$^2$m$^{-4}$s$^{-1}$K$^{-2}$ obtained from the experiment above can also be obtained using values within the ranges given in the Goodfellow tabulated data above. In this work the following values were used:

- Thermal conductivity $K$: 0.4 Wm$^{-1}$K$^{-1}$
- Density $\rho$: 1360 kgm$^{-3}$
- Specific heat $C$: 1290 JK$^{-1}$kg$^{-1}$

This gives a thermal inertia $K\rho C$ of $7.02 \cdot 10^5$ J$^2$m$^{-4}$s$^{-1}$K$^{-2}$ which is in good agreement with the experimental value.

The heat release for the combusting needle felt, or PET, was taken from Johansson and Axelson from an experiment conducted using an irradiation of 50 kW/m$^2$ in the cone calorimeter [4]. The heat release curve is shown with a black solid line in Figure 35 below.
Figure 35. HRRPUA (Heat Release Per Unit Area) from the needle felt. The black solid line shows the measured HRRPUA [4] while the pink dashed line shows the HRRPUA ramp function used in the model.

The material of the ceiling is also assumed to be needle felt. However, if the entire ceiling is modelled as a piece of needle felt the fire propagation will be very rapid. Further, studying the interior of various buses shows that the ceiling is often more complex with only parts clad with needle felt. Consequently the ceiling is modelled as piecewise clad with needle felt and piecewise with a non-combustible material. The importance of the ceiling configuration for flame spread is studied in section 7.4.3.

7.3.3.3 Floor

The floor is assumed to be made of PVC. The properties for PVC are [12]:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity</td>
<td>0.12-0.25 Wm(^{-1})K(^{-1}) (at 23°C)</td>
</tr>
<tr>
<td>Density (\rho)</td>
<td>1400 kgm(^{-3})</td>
</tr>
<tr>
<td>Specific heat (C)</td>
<td>1000-1500 JK(^{-1})kg(^{-1})</td>
</tr>
</tbody>
</table>

No experimental investigation of thermal inertia and ignition temperature was conducted for the floor material. The thermal properties used in FDS4 are the average values of the tabulated material data, that is:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity</td>
<td>0.185 Wm(^{-1})K(^{-1})</td>
</tr>
<tr>
<td>Density (\rho)</td>
<td>1400 kgm(^{-3})</td>
</tr>
<tr>
<td>Specific heat (C)</td>
<td>1250 JK(^{-1})kg(^{-1})</td>
</tr>
</tbody>
</table>

The ignition temperature for PVC carpet depend on the type of PVC used. In this work an ignition temperature of 280°C has been used [13]. In a commonly used source for ignition temperatures the values range between 240°C and 441°C for piloted ignition, depending on the type of PVC [8].
The heat release for burning PVC-floor material was measured by Johansson and Axelsson using an irradiation of 25 kW/m² [4]. The heat release curve is shown with the black solid line in Figure 36 below.

![Figure 36. HRRPUA (Heat Release Per Unit Area) from the PVC carpet. The black solid line shows the measured HRRPUA [4] while the pink dashed line shows the HRRPUA ramp function used in the model.](image)

7.4 Results from the simulations

In this section the results from the simulations of the scenarios mentioned in section 7.1 are presented.

7.4.1 Effect of open roof hatches

A comparison of the smoke distribution in the bus with open and closed roof hatches is given in Figure 37. The smoke gas layer is established much closer to the floor when then roof hatches are closed. This comes as no surprise but it emphasizes the efficiency of open roof hatches in the ventilation of smoke. An electric opening system that can be triggered by the driver is an interesting option to ensure optimal smoke ventilation in a fire situation. This could be very useful in improving the conditions inside the bus when there is a fire but the bus needs to continue driving, e.g., in tunnels.
7.4.2 Effect of open doors

The importance of smoke ventilation through the doors is illustrated in Figure 38. In the left columns the doors are open while in the right column the doors are closed. The roof hatches are closed in both cases. In order to illustrate the heavy smoke density when doors are closed the bus has been cut in such a way that the right wall has been removed in the visualization. This has no impact on the simulations. It should be noted that removing the right wall means that everything that is on the right hand side of the bus also disappears from the illustrations. The smoke plumes exiting through the doors are therefore not seen in the images in the left column. As can be seen in Figure 38 the entire bus is smoke filled within three minutes.
7.4.3 Effect of distribution of needle felt in ceiling

In this example flame spread is included in the model. This means that all the material parameters described in section 7.3.3 above are used to simulate how the fire propagates between the surfaces in the bus. It must be emphasized that flame spread is a very complex phenomenon and while it is difficult to correctly formulate and solve the equations describing flame spread it is even more difficult to obtain correct material parameters that describe the materials throughout the combustion process. Therefore the results should be considered as qualitative indications of the expected behaviour, and not as quantitative data that exactly describe the propagation of the flame front in the bus.

The figures below show how the fire propagates from the seat to the ceiling and thereafter spread mainly in the upper part of the bus. The dark stripes in the ceiling correspond to needle felt. The brighter stripes correspond to areas with non-combustible material. The bus is shown from different angles in the different figures in order to illustrate what is happening at each instant. Only the flames from the fire are visualized, not the spread of smoke.
Figure 39. After 2 min. The flames from the seat has just spread to the ceiling above the rear window.

Figure 40. After 3 min. The fire spreads along the ceiling.
Figure 41. After 4 min. The fire has spread over all the needle felt in the rear part of the bus. No seats have yet been ignited.

Figure 42. After 5 min. Flames is escaping through roof hatches and rear door. The fire spread is still concentrated to the upper part of the bus. The seat nearest the ignition source has caught fire.

Figure 43. After 6 min. A flashover has occurred and all combustible material in the bus will soon be combusted. The main route for the flame spread has been the needle felt in the ceiling. It is clear that a limitation of the amount of combustible material in the ceiling would slow down the fire propagation in the bus.

It is clear that the existence of a combustible material in the ceiling greatly enhances flame spread. Although only half the surface in the ceiling is covered with needle felt this
is still the main route for fire propagation. The spread of fire between seats is much slower.

7.4.4 Grid size analysis

Simulations have been performed with 5 cm and 10 cm grid cells. Figure 44 shows the smoke production and transport. No flame spread is included in the model. It should be noted that the two simulations, using 5 cm and 10 cm grid cell size, simulate the same scenario, meaning that they should produce identical results. This is obviously not the case.

![Figure 44. Results with 10 cm and 5 cm grid cell size, respectively, at different times from start if ignition of the seat. The burning seat is behind the wall at the rear end (left) of the bus. The reason why the seats are seen through the wall for the images with 10 cm grid cell is that the visualization software does not fully distinguish between wall and seats. This has no effect on the simulation results.](image)

One commonly used parameter when considering the grid size is the so called characteristic fire diameter [2]. The details of the parameter will not be discussed here but for the heat release rates that are relevant for the burning seat, that is around 250 kW, the characteristic fire diameter is 0.5 m. According to previous studies on the grid size sensitivity of FDS4 it has been found that the ratio between characteristic fire diameter and grid cell size should be around 5-10 in order to obtain an acceptable quality on the results without compromising the computational time too much [14,15]. This correlates well with the fact that very different results are obtained with 10 cm and 5 cm grid cell size. Using a coarse grid with 10 cm calls gives a ratio of 5 between the characteristic fire diameter and the grid cell size. This is at the low end of what has been found acceptable in the literature. Decreasing the grid cell size to 5 cm gives a ratio of 10, which is clearly acceptable according to earlier findings. Therefore, 5 cm grid cells have been used in all simulations in this project. The dependence of the results on the grid cell size needs to be studied further.
7.5 Conclusions

The roof hatches are very effective in ventilating fire smoke. Therefore automatic opening of roof hatches triggered by the driver would be useful, e.g., when a fire breaks out inside the bus when it is traveling through a tunnel.

The upper part of the bus will quickly be obscured in the event of a fire. This will happen even if roof hatches and doors are open. Emergency opening handles are typically found near the upper parts of the doors. They will therefore be obscured within a minute after the fire has started. In this perspective it could be a good idea to move the emergency opening handles to a lower position.

It has been found in this particular model that needle felt in the ceiling is the main route for fire propagation through the bus. Therefore a limitation of combustible material in the ceiling would slow down the overall fire propagation in the bus.

The results depend on the grid size. This is a troublesome situation and further studies are necessary in order to confirm the quality of the simulations.
8 Real scale bus fire tests

A conventional coach for 49 passengers was used for three different real scale tests. In order to obtain as much information as possible a number of interrupted tests were made before letting the fire progress through the whole bus. It was desired to obtain information on escape possibilities during a developing fire and the possible consequences of an uncontrolled fire for the surroundings. To summarise, the main objectives of the test series were to evaluate:

- Fire detection in the engine room
- Fire resistance of the top fire barrier of the engine room
- The consequences of a tyre fire and the window fire resistance
- Fire development from the rear compartment into the passenger compartment
- Smoke spread and visibility in the passenger compartment
- Concentrations of toxic gases in the passenger compartment
- Heat release rate from a developed fire in the coach.

The test programme was divided into three main parts:

- Engine room fire with detection, Test 1
- Fire in wheel house and tyre, Test 2
- Fire in rear luggage compartment, to simulate a rear engine, allowed to develop until flashover, Test 3.

A 13 m coach, with 49 passenger seats, was made available for fire testing from Volvo Buses AB, see Figure 45. The bus had mainly been used for development purposes and never used in public traffic. The interior was fully furnished and the gear box was fitted with a retarder to be able to simulate a loaded engine and reach higher engine temperatures.

Figure 45. The coach used in the real scale test series.
8.1 Test 1 - Fire in engine compartment with fire detection

Test 1 was a test with fire in the engine room as described below.

8.1.1 Test 1 – Procedure and preparations

This test was intended to simulate a fuel fire in the engine compartment. A mixture of diesel, engine oil, hydraulic oil and sawdust was used as fire source and placed on top of the engine block as shown in Figure 46. The fuel mixture and application procedure followed the recommendations in SBF 128 [16]. Before ignition of the fuel mixture the engine was run for at least 10 minutes, with loading via the retarder in the gearbox. When the fuel mixture was ignited the engine was put in a no-load running condition.

![Image of fuel mixture application to engine block]

Figure 46. Application of the fuel mixture to the engine block. TC 38-40 indicate position of thermocouples.
Figure 47. The thermocouples (TC 41 – 47) and the smoke detectors B2 och B3 in the luggage compartment over the engine.

A summary of the events during the test is given in Table 15 below.

**Table 15. Time table over actions and observations during the test.**

<table>
<thead>
<tr>
<th>Time</th>
<th>Actions</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>Start measuring</td>
<td>The engine had been running for ~10 min.</td>
</tr>
<tr>
<td>02:45</td>
<td></td>
<td>M1. Alarm, smoke, aspirating system. See Figure 62.*</td>
</tr>
<tr>
<td>05:00</td>
<td>Ignite the fuel mixture in the engine compartment.</td>
<td>The temperature of the engine body was ~90°C.</td>
</tr>
<tr>
<td>05:10</td>
<td></td>
<td>Temperature increase in the engine compartment</td>
</tr>
<tr>
<td>05:16</td>
<td></td>
<td>Alarm, smoke, B3*</td>
</tr>
<tr>
<td>05:17</td>
<td></td>
<td>Alarm, smoke, B2*</td>
</tr>
<tr>
<td>05:19</td>
<td></td>
<td>Alarm, smoke, B4*</td>
</tr>
<tr>
<td>05:19</td>
<td></td>
<td>Alarm, smoke, B1*</td>
</tr>
<tr>
<td>05:30</td>
<td></td>
<td>The air system is punctured.</td>
</tr>
<tr>
<td>06:00</td>
<td>Stop the engine (the engine compartment ventilation stops)</td>
<td>The smoke begin to be darker</td>
</tr>
<tr>
<td>06:05</td>
<td></td>
<td>The engine fire dies caused by low oxygen level</td>
</tr>
<tr>
<td>07:15</td>
<td></td>
<td>Cooling water leaks out on the floor.</td>
</tr>
<tr>
<td>09:30</td>
<td></td>
<td>Open the engine room and extinguish.</td>
</tr>
<tr>
<td>11:00</td>
<td></td>
<td>The plywood hatches is opened and the engine is powdered by CO₂</td>
</tr>
<tr>
<td>12:00</td>
<td></td>
<td>Alarm, heat, B2*</td>
</tr>
<tr>
<td>13:45</td>
<td></td>
<td>Alarm, smoke, K:1.3, see Figure 62.*</td>
</tr>
</tbody>
</table>

* Location of the smoke alarm, se figure 62.
Important observations from the test are:

- 2:15 minutes before igniting the fuel mixture on the engine, the aspirating detection system M1 identified smoke in the engine compartment, probably caused by fumes from the rear axis brakes and evaporated oil in the engine compartment.
- About 1:15 minutes after the engine was stopped, the fire ran out of oxygen in the engine compartment. This was due to the fact that the cooling fan stopped when the motor stopped.
- The smoke detectors (B1-4) located in the luggage compartment in front of, over, and behind the engine compartment were activated about 15 – 20 seconds after ignition.
- The plywood hatch over the engine compartment was slightly damaged after the fire. Just the surface layer was been charred, see Figure 49.

Figure 48. The fire in the engine compartment kept on burning for about two minutes. The engine was switched of one minute after ignition of the fuel mixture.

Figure 49. The engine room after test 1C with the underside of the burnt plywood visible. The depth of the charred plywood was about 2 – 3 mm.
The test showed that:
- In a closed engine compartment without ventilation the fire will very soon run out of oxygen.
- A rapid detection system together with an immediate stop of the engine will probably give a minor damage in the engine compartment and no or limited spread of the fire to other parts of the bus.

8.2 Test 2 - Fire in a wheel house and tyre

This test was conducted to demonstrate the possible consequences of a wheel house fire. To ignite the tyre, the wheel was placed in a small pan with a kerosene – diesel mixture (PD) and cotton fabric soaked with PD was placed around the tyre. To prevent fire damage on the floor and side walls of the bus, the wheel house and parts of the side wall were insulated with mineral wool as seen in Figure 50. The distance from the top side of the rear tyre to the side window was 1,2 m. There were two thermocouples (TC 48 – 49) on the outside of the window, to indicate the temperature of the window and the heat from the fire.

To speed up the ignition of the tyre the wheel was standing in a small pan with a kerosene – diesel mixture (PD). Cotton fabric soaked with the PD was also placed around the tyre.

Figure 50. The test set up before igniting the tyre
A summary of the events during the test is given in Table 16 below.

**Table 16. Time table over actions and observations during the test.**

<table>
<thead>
<tr>
<th>Time</th>
<th>Actions</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>Start measuring</td>
<td></td>
</tr>
<tr>
<td>01:00</td>
<td>Signal with the horn</td>
<td>Synchronization signal for video cameras</td>
</tr>
<tr>
<td>02:00</td>
<td>Igniting the tyre</td>
<td>Two litre of photogene – diesel mixture (PD) for igniting</td>
</tr>
<tr>
<td>02:30</td>
<td></td>
<td>The fire reaches the roof (just PD burning)</td>
</tr>
<tr>
<td>03:00</td>
<td></td>
<td>The fire reaches the lower edge of the window</td>
</tr>
<tr>
<td>04:00</td>
<td></td>
<td>The rubber tyre is burning. The air suspension system is leaking.</td>
</tr>
<tr>
<td>05:00</td>
<td></td>
<td>The plastic mudguard, behind the tyre, is burning</td>
</tr>
<tr>
<td>07:00</td>
<td></td>
<td>Smoke in the passenger compartment</td>
</tr>
<tr>
<td>10:00</td>
<td></td>
<td>The fire increases</td>
</tr>
<tr>
<td>12:30</td>
<td></td>
<td>The aluminium plate is melting</td>
</tr>
<tr>
<td>14:00</td>
<td></td>
<td>Poor visibility in the passenger compartment</td>
</tr>
<tr>
<td>16:00</td>
<td></td>
<td>Small smouldering and smoke in the coach</td>
</tr>
<tr>
<td>17:00</td>
<td></td>
<td>The window is still not broken</td>
</tr>
<tr>
<td>17:05</td>
<td>Extinguishing</td>
<td>Extinguishing with water</td>
</tr>
</tbody>
</table>

The fire flames did not cover the window because of the distance between the tyre and window (1.2 m) as seen in Figure 52. However, smoke, and subsequently the fire, was transported into the passenger compartment from the wheel house via the floor and side wall. Therefore it was decided to extinguish the fire as a small fire was growing inside the passenger compartment and the bus should be used for more fire experiments.

The window was in good shape until the fire was extinguished with water.

The sudden cooling from the water broke the outer glass in the window as seen in Figure 52. The possibility of burning-through a side window is greater for a city bus than for a coach since the time until burn-through varies with the distance between the window and the wheel house.

Typical distances, tyre – window, are
- 0.3-0.4 m for City buses,
- 0.6-0.8 m for Inter City buses
- 1.0-1.3 m for Coaches.

A bus tyre needs a lot of heating energy to catch fire. The cause of a fire in a tyre is normally heat caused by friction from malfunctioning brakes or wheel bearings. There are, however, also accidents when a ragged tyre has been able to cause a fire. A device for indicating high temperatures in the wheel bearings could prevent many wheel house fires.
Figure 52. The outer of the two glasses was cracked caused by the extinguishing water.

Figure 53. The temperatures, measured by two thermocouples, on the window, see also Fig. 50.

The test showed that:
- The distance between tyre and side window can improve fire resistance
- The risk for burning-through in a side window is higher for a city bus than for a coach
8.3 Test 3 - Fire in the rear luggage compartment allowed to develop until flash-over

The scenario is a fire in the engine compartment in the rear end of the coach. The fire is then free to develop into the passenger compartment and continue to the rest of the coach. There is a limit on the fire size allowed since too high a heat release rate will damage the measuring equipment and be dangerous to staff.

The aim of this test was to investigate:
- Fire development from the rear luggage compartment into the passenger compartment
- Smoke spread and visibility in the passenger compartment
- Concentrations of toxic gases in the passenger compartment
- Heat release rate (HRR) from a developed fire in the coach.

The visibility investigation was conducted in order to show how the passengers will perceive the reduced visibility inside a bus during a fire. The smoke propagation in the passenger compartment was recorded by four video cameras placed at different levels (eye level, top of backrest level and floor level). White markers (about 1 dm²) with figures in the passenger compartment were used to estimate the length of visibility.

The conditions during the test were:
- The front and middle doors were open
- All roof hatches were closed
- The roof lightning was switched on
- The lightening under the luggage racks was switched on
- There was also lightening along the floor between the seat rows.

The fire started in the rear luggage compartment in the coach. The fire source was a propane burner with the power of 100 kW. The rear luggage compartment was prepared with ventilation holes in the floor to simulate the ventilation in a real engine compartment. There were also side walls, of mineral wool, around the propane burner in order to focus the fire to a specific measuring surface. A photo of the set-up is provided in Figure 54.
The floor inside the passenger compartment over the propane burner was prepared with thermocouples to indicate the fire resistance of the floor as shown in Figure 55.

Figure 55. The floor over the propane burner in the passenger compartment. The thermocouples TC 20 – 21 are located about 20 cm above the floor.

There were two thermocouple trees, front and rear, in the centre of the passenger compartment, to measure the vertical propagation of hot gases. The thermocouple trees are shown in Figure 56. There were also markers on the backrest, to estimate the length of visibility, when the smoke obscuration increased in the passenger compartment.

Figure 56. The passenger compartment with two thermocouple trees, markers at the backrest and two lines with thermocouples at the top of the backrests. To the right there is a sketch over the thermocouple tree with distance from the ceiling in mm.
In the centre of each seat line, on top of the backrest, there was a thermocouple line to measure the horizontal propagation of the hot gases, see Figure 56 and Figure 57. The top corner of some backrests had markers with numbers to indicate the visibility length as indicated in Figure 57.

![Thermocouples along the seat lines and Markers at the backrests](image)

**Figure 57.** Markers at the backrests and thermocouples along the seat lines.

The toxic gases in the passenger compartment were measured using an FTIR (Fourier transform infrared spectroscopy). The position of the sample probe is shown in Figure 58 below.

![Gas sampling tube in the centre of passenger compartment and entrance of the sampling probe](image)

**Figure 58.** Left picture: The gas sampling tube in the centre of passenger compartment (about 1750 mm from the floor). Right picture: The entrance of the sampling probe as seen from outside the bus. There is a heater on the conduit in order to avoid condensation of the sampled gases.

The visibility in the passenger compartment during the smoke development was video recorded with four cameras. The position of the cameras is shown in Figure 62. Photos of the front video camera are shown in Figure 59 below.
To prevent the smoke and hot gases from going out through the front door, the upper edge was lowered with a soffit to the same level as for the middle right side door, see Figure 60 below.

Figure 60. The upper edge was lowered using a plywood soffit.
The Heat release rate (HRR) was measured using SP’s Industry calorimeter. The hood is shown in Figure 61.

Figure 61. The Industry calorimeter over the rear part of the coach (cover ~ 2/3 of the length).

A lay-out of the coach with detectors and measuring equipment is given in Figure 62 below.

Figure 62. A lay-out of the detectors and measuring equipment in the coach.
An account of events during the test is given in Table 17.

Table 17. Time table over actions and smoke observations during the test.

<table>
<thead>
<tr>
<th>Time</th>
<th>Actions</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>Start measuring</td>
<td></td>
</tr>
<tr>
<td>01:00</td>
<td>Signal with the horn Synchronization signal</td>
<td></td>
</tr>
<tr>
<td>02:00</td>
<td>Ignition</td>
<td></td>
</tr>
<tr>
<td>04:00</td>
<td>Light smoke from the luggage compartment over engine.</td>
<td></td>
</tr>
<tr>
<td>05:00</td>
<td>Light smoke in the passenger compartment but still good visibility. The smoke is cold and therefore spread out in the whole volume.</td>
<td></td>
</tr>
<tr>
<td>07:30</td>
<td>Heavy cold smoke in the whole passenger compartment. The close to zero in the rear part of the coach and less than 3.5 m in the front of the coach.</td>
<td></td>
</tr>
<tr>
<td>19:00</td>
<td>400°C at the floor</td>
<td></td>
</tr>
<tr>
<td>20:00</td>
<td>Extinguish</td>
<td></td>
</tr>
</tbody>
</table>

The heat release rate from the bus fire is shown in Figure 63. Due to overflow in the measuring system we had to cancel the measurement at the time 19 minutes and 12 MW (red circle). We estimate the total HRR at 20 minutes to reach a level between 15-20 MW.

![Figure 63. The heat release rate from the burning coach during the test.](image)

Estimation of the total HRR at 20 minutes is ~ 15 - 20 MW. The extinction of the fire started after 20 minutes.
Table 18. Observations from the coach during the HRR measurement

<table>
<thead>
<tr>
<th>Actions</th>
<th>Time</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start measuring</td>
<td>00:00</td>
<td></td>
</tr>
<tr>
<td>Ignite</td>
<td>02:00</td>
<td></td>
</tr>
<tr>
<td><strong>07:00</strong></td>
<td></td>
<td>The material starts to burn in the rear luggage compartment</td>
</tr>
<tr>
<td>10:50</td>
<td></td>
<td>The left side panel of the rear luggage compartment fell of</td>
</tr>
<tr>
<td><strong>11:10</strong></td>
<td></td>
<td>Fire out of the centre luggage compartment, rear section</td>
</tr>
<tr>
<td>11:20</td>
<td></td>
<td>Fire out of the centre luggage compartment, centre section</td>
</tr>
<tr>
<td><strong>11:30</strong></td>
<td></td>
<td>Fire flames up over the roof, from the rear wall</td>
</tr>
<tr>
<td><strong>12:45</strong></td>
<td></td>
<td>Fire out of the centre luggage compartment, front section</td>
</tr>
<tr>
<td>14:00</td>
<td></td>
<td>Fire flames, out of the left rear wheel house and side panel under the side window No 3</td>
</tr>
<tr>
<td>16:00</td>
<td></td>
<td>The fire increase rapidly from the left rear wheel house</td>
</tr>
<tr>
<td><strong>16:55</strong></td>
<td></td>
<td>Side window No 3, left side, collapses</td>
</tr>
<tr>
<td><strong>17:00</strong></td>
<td></td>
<td>Fire through the roof over side window No 3</td>
</tr>
<tr>
<td><strong>17:30</strong></td>
<td></td>
<td>Side window No 5, left side, collapses</td>
</tr>
<tr>
<td><strong>17:40</strong></td>
<td></td>
<td>Side window No 4, left side, collapses</td>
</tr>
<tr>
<td><strong>19:00</strong></td>
<td></td>
<td>There is a big hole in the heat gas collector, of the Industry Calorimeter, over the coach.</td>
</tr>
<tr>
<td>Extinguishing</td>
<td>20:00</td>
<td></td>
</tr>
</tbody>
</table>

Comments on the observations

The following main observations were made during the tests:

- At ~ 11 minutes, the central luggage compartment was compromised and large flames extended outside the coach.
- At ~ 17 minutes the side windows on the left hand side of the bus broke and the interior material started to burn with high intensity.
- At 19 minutes the HRR level decreased because of a large hole in the fire hood collecting the fire gases, over the rear part of the coach. If the fire hood had remained intact, we estimate the top level of the HRR would have been approximately 14 – 15 MW before the fire was manually extinguished. This relatively low level is because only three side windows broke, causing the fire in the bus to be severely vitiated. If three side windows had broken on each side of the coach (~ 7 meter ventilation) the estimated HRR level could have reached 25 MW.

Figure 64 to Figure 66 show the visibility determined using camera No 1. This camera was at eye level, and most representative for the visibility in the coach. The ceiling lights also significantly increased the visibility. The smoke in the passenger compartment was "cold" which resulted in a more homogeneous distribution. When the smoke is hot, this results in smoke layering under the ceiling and much better visibility at the floor level.
Figure 64. The visibility from camera No 1, in ceiling lamp height.

Figure 65. The visibility from camera No 1, in the eye level.

Figure 66. The visibility from camera No 1, in the backrest level.
Figure 67 to Figure 71 show the temperature development in selected parts of the bus.

Figure 67. Fire resistance in the floor over the gas burner. See also Figure 55.

Figure 68. The rear thermocouple tree. TC 22 is 50 mm from the ceiling and TC 29 is 1900 mm from the ceiling.

Figure 69. The front thermocouple tree. TC 30 is 50 mm from the ceiling and TC 37 is 1900 mm from the ceiling.
Figure 70. Temperatures above the seats on the right side of the bus. See also Figure 56 and Figure 62.

Figure 71. Temperatures above the seats on the left side of the bus. See also Figure 56 and Figure 62.
Figure 72 to Figure 75 show how the concentration of toxic gases changes with time. The position of the sample probe is indicated in Figure 58.

**Figure 72.** The concentration of CO in the passenger compartment during the first 8 minutes. Dangerous concentrations after ~ 5 minutes.

**Figure 73.** The concentration of CO₂ in the passenger compartment during the first 8 minutes.

**Figure 74.** The concentration of HCl in the passenger compartment during the first 8 minutes.
Figure 75. The concentration of HCN in the passenger compartment during the first 8 minutes.

Table 19 summarises the measured concentrations of toxic gases. A comparison with recommended exposure limits is also given. The exposure limits are defined according to the following recommendations:

- **TWA**: Time-weighted average concentrations for up to a 10 hour workday during a 40-hr workweek.
- **STEL**: Short-term exposure limit of 15-minute exposure that should not be exceeded at any time during a workday.
- **IDHL**: Concentrations immediately dangerous to life or health.

Table 19. The toxic gases measured by the FTIR, including toxic hygienic limit values.

<table>
<thead>
<tr>
<th>Name</th>
<th>Gas</th>
<th>Max. measured value [ppm]</th>
<th>TWA [ppm]</th>
<th>STEL [ppm]</th>
<th>IDLH [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>CO</td>
<td>3030</td>
<td>35</td>
<td>200 (100)</td>
<td>1.200</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO²</td>
<td>1710</td>
<td>5.000</td>
<td>30.000 (10.000)</td>
<td>40.000</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>HCl</td>
<td>51</td>
<td>5</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Hydrogen cyanide</td>
<td>HCN</td>
<td>65</td>
<td>2</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Hydrofluoric acid</td>
<td>HF</td>
<td>&lt; 5</td>
<td>3</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Hydrobromic acid</td>
<td>HBr</td>
<td>&lt; 10</td>
<td>3</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>SO₂</td>
<td>&lt; 10</td>
<td>2</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Nitrogen oxide</td>
<td>NOa</td>
<td>&lt; 15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>NO₂</td>
<td>&lt; 5</td>
<td></td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 76 to Figure 90 below show some photos from the test.

Figure 76. Igniting the propane gas burner (100 kW). The time: 02:00 minutes

Figure 77. 2:00 minutes after igniting.
Figure 78.  3:00 minutes after igniting.

Figure 79.  5:30 minutes after igniting.
Figure 80.  7:00 minutes after igniting.

Figure 81.  9:30 minutes after igniting.
Figure 82.  10:30 minutes after igniting.

Figure 83.  13:30 minutes after igniting.
Figure 84.  16:00 minutes after igniting.

Figure 85.  18:00 minutes after igniting.
Figure 86.  18:00 minutes after igniting. Extinguishing of safety reason.

Figure 87.  The left side of the coach after test.
Figure 88. The rear side of the coach after test.

Figure 89. The rear part of the passenger compartment after test.
The following conclusions were drawn from the test:

- The time for evacuation of the passenger was a maximum of 4 – 5 minutes in this particular test. This might be enough when the coach stands still on the road without any damage. However, in case of a fire together with a collision or if the bus has rolled over the risk of a disaster is very high.
- After 4 -5 minutes the concentration of toxic gases reaches a dangerous level and the visibility in the passenger compartment decreases rapidly.
- After 5 – 6 minutes the visibility is just a few meters with all lighting on (roof lamps, reading lamps and guiding lights on the floor). The estimation of time for evacuation is 2 – 4 minutes without lights in the coach, depending on the level of the daylight.
- The rapid increase of the fire in the coach indicates a severe risk of danger for human beings in a tunnel or an underground bus station. The flashover occurred within 15 minutes.
- The floor of the passenger compartment made of plywood and the double glazed side windows gave good fire resistance (integrity) in the passenger compartment. Laminated windows give even more time to the fire resistance.
9 Discussion, conclusions and recommendations

The full scale test showed that smoke and toxic gases reached lethal levels in the passenger area within a few minutes, despite the fact that the fire started outside of the passenger area, in the rear compartment. This indicates a number of flaws which are characteristic of buses. The first is that the smoke was easily transported into the passenger area. Better partitions between different compartments are therefore desirable. The second is the rapid spread of the fire into the passenger area and the interior materials. This illustrates the need for stricter regulations regarding the fire performance of interior materials in buses. Bus fire safety is lagging behind that of other vehicles in terms of fire safety. Finally it is clear that the time available for escape is very limited. Thus a fire detection system will save very valuable time if it is installed in such a way that it gives early warning of fire or of overheating.

9.1 Statistical evidence

Figure 91 –94 show the number of bus fires and the breakdown of causes of fires in Norway and Sweden between 1997 and 2004. The numbers indicate that 1.0-1.4 % of all buses and coaches in service are involved in fires each year. This is an unacceptably high level since, in percentage terms, about 5-10 times as many buses and coaches catch fire as do heavy goods vehicles.

![Number of fires in Norway](image)

Figure 91 The number of bus or coach fires in Norway, 1997-2004.
Figure 92  Breakdown of causes of fires in Norway over the period 2001–2004: Mean values.

Figure 93  The number of bus or coach fires in Sweden, 1996-2004.
9.2 Reduced fire risk through improved interior materials

Current requirements on the fire performance of interior materials of buses are based on tests using the ISO 3795/FMVSS 302 test method. This method has already attracted much criticism and it has also been shown in this project that it is inadequate in discriminating between materials with different fire safety performance.

Figure 94 and Figure 95 below show how more or less all materials pass the existing requirements illustrating the inability of the ISO 3795/FMVSS 302 test to adequately discriminate between materials with different fire safety performance.
The main conclusions from the review of interior materials were:

- All materials except one fulfil the requirements in the present European vehicle directives and are far below the criteria.
- When tested in methods required for passenger ships most products do not fulfil the criteria for smoke production.
- Several of the tested products would most likely not be allowed in public spaces or in escape routes in buildings in Europe. The results indicate that some of them would produce flashover in less than two minutes if mounted on the walls and ceiling in a small room and exposed to a corner fire.
- When compared to the proposed European standard for fire safety in passenger trains, most products do not fulfil the requirements neither in terms of heat release nor in terms of smoke production.
- The above results clearly indicate that the presently used test method (ISO 3795) yields a low level of safety for bus passengers in case of a fire. The low fire safety level can easily be improved using modern test methods that can differentiate between different fire performance. It would be beneficial to use experience from existing or proposed requirements from in other areas.
- Other research in the same area has come to the same conclusions as in this project.

An obvious conclusion from the results is that the ISO 3795/FMVSS 302 test method is inadequate when it comes to discriminating between different levels of safety performance of interior products for buses. Therefore an initiative has been taken at GRSG (Groupe de rapporteurs sécurité générale) at UNECE (United Nations Economic Commission for Europe) to change these regulations. The aim is to amend Regulation No. 118 where it is presently specified that ISO 3795/FMVSS 302 is the test to which bus interior materials should comply. The proposed amendment contains other and better methods that are presently employed by IMO (International Maritime Organization) and in the new EN-standard for fire safety of trains.
9.3 Reduced fire risk by improved design, routines, and materials

Most bus fires start in the engine compartment or surrounding areas. In addition, fire can start in the electrical system in the bus and the wheels houses, as well from arson on the bus. In order to reduce the number of fires in buses, the following recommendations are given:

- Improved design
  - Separate components where there is a risk of combining: heat, fuel and oxygen.
  - Insulate all hot surfaces in the engine compartment (thermal insulation).
  - Lower the average temperature in the engine compartment and other vital locations to increase the lifetime of polymer materials.
  - Separate the electrical system into subsystems which can easily, even automatically, be disconnected in case of a fire risk. Keep a basic system of engine and exterior lighting to help drive the bus if necessary. This should not be confused with normal fused circuits.
  - Create a new standard for fuses that makes it more difficult to switch to stronger fuses in the same fuse holders.
  - Eliminate mechanical fatigue and other physical effects that can lead to a fire.
  - Specify (regulate) minimum spaces in the engine for higher quality of maintenance.

- Improved routines
  - Ensure quality of service and repairs through staff training, appropriate time allowance, and choosing the correct spare materials. Basic training concerning fire risks should be included in all training of the engineering staff.
  - Educate drivers in fire fighting and fire risks.

- Improved materials
  - Impose stricter requirements on interior materials.
  - Improve fire resistance of partitions, thereby reducing spread of smoke and fire.
  - Equip the engine compartment with better detection system, in combination with fire extinguish system.
9.4 Reduced fire risk by improved fire resistance

Experience from the full scale test with the coach demonstrates clearly that a better fire resistance between the passenger compartment and other parts of the bus would have extended the time for evacuation of the bus. Smoke and toxic gases spread rapidly into the passenger area of the bus. The time before the fire entered into the bus would also have been increased with better fire resistance introduced around the engine compartment. Fire resistance can be defined into terms of the following characteristics:

- **E** Integrity (tightness)
- **I** Insulation
- **K** Fire protection (inflammable cladding)
- **S** Smoke resistance

These four characteristics are also applicable in buses. Integrity (E) is the ability of a dividing wall to stop the fire and remain whole. Isolation (I) prevents high temperatures on the floor and wall surfaces from being transferred into the passenger compartment. Fire protection (K) is protective cladding that prevents the fire from weakening surrounding structures. The smoke resistance (S) is the ability to prevent smoke and toxic gases from entering the passenger spaces through a dividing wall.

Integrity, insulation and fire protection can be tested in the mini furnace we used in our testing. Smoke resistance can be tested in a separate oven with overpressure. We believe that the requirements set by these properties will enhance the possibility for evacuation and thereby save more passengers. The mini furnace described in chapter 7 can relatively easily be written up as a standard test method for use in connection with vehicles.

The requirements need to be differentiated according to the burning behaviour and intensity. A possible division into risk zones and requirements is summarised in Table 20.

<table>
<thead>
<tr>
<th>No</th>
<th>Position</th>
<th>Risk</th>
<th>Requirement (Integrity) [min.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Engine compartment</td>
<td>High</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>Luggage compartment</td>
<td>Low</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Electric distribution box area²</td>
<td>Medium</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Wheel houses</td>
<td>Medium</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>The remaining spaces under the bus floor</td>
<td>Low</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Muffler space</td>
<td>Medium</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>Space for electrical devices like fans, batteries, etc.²</td>
<td>Medium</td>
<td>10</td>
</tr>
</tbody>
</table>

1. Requirements in minutes, according to the specified method above (the mini furnace)
2. The through burning time is lower as the electrical fires are often slow, compared to liquid fires.

9.5 Reduced fire risk by fire fighting in engine compartment

Most bus fires start in the engine compartment. Yet there exists no useful test methods for extinguishing systems in engine compartments. Therefore a new test method was developed and presented in section 6. The target in this part of the project was to develop a method which represents all the characteristics of a real engine compartment and
contains the same conditions with respect to the fire. The method is intended primarily for testing of water-based extinguish systems, but can also be used for other extinguish agents. The major advantages of this method are:

1. It is a model of an engine compartment in a bus, but can also be used for other types of vehicles.
2. The method contains all the conditions prevalent in a real engine compartment, with respect to: temperatures, radiation, fuel and air flow.
3. The test is divided into different difficulty levels corresponding the operating conditions: A. The bus on the road with loaded engine, B. The bus parked with the engine idling and C. A parked bus with the engine switched off.
4. Fire sources, temperatures and air flows can be specified which translates into well defined conditions.

These characteristics meet the requirements for an internationally competitive test standard. To obtain a manageable size, it was decided to make the test room in a reduced scale, 1/3 of a normal engine compartment of a city bus. This results in the same temperatures as for the full size, but the dimensions of the various parts of the test, and the size of the fire and amount of fuels is 1/3 of the full size. Further, 1/3 of the nozzles intended for the end use application should be used in the test.

The operating conditions are shown in Table 21.

<table>
<thead>
<tr>
<th>Engine</th>
<th>Ventilation</th>
<th>Exhaust system</th>
<th>Engine body</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Loaded</td>
<td>High</td>
<td>600 ºC</td>
<td>95 – 100 ºC</td>
</tr>
<tr>
<td>B. Idling</td>
<td>Low</td>
<td>600 ºC</td>
<td>~ 90 ºC</td>
</tr>
<tr>
<td>C. Shut of</td>
<td>Very poor</td>
<td>500 and decreasing</td>
<td>~ 90 ºC Slowly decreasing</td>
</tr>
</tbody>
</table>

The detailed test program for an extinguishing system is presented below. The criteria for complying with class A, B, and/or C is that the tested system manages to extinguish the fire.

<table>
<thead>
<tr>
<th>Classification</th>
<th>[Air speed]</th>
<th>Spray fire</th>
<th>3 diesel fires</th>
<th>Smouldering fires</th>
<th>Temperatures [ºC]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A [4,33 m/s]</td>
<td>Bus on plane road, full with passenger.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>B [1,5 m/s]</td>
<td>Parked with engine running.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>C [1,1 m/s]</td>
<td>Engine stopped (parked)</td>
<td>No [2]</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

1. The air flow is measured in the centre of the air outlet in the floor
2. There are no pressure in the liquid systems when the engine is stopped.
9.6 Reduced fire risk by computer aided design

It was shown that CFD (Computational Fluid Dynamics) can be a useful complement to full scale testing especially when the movement of smoke and heat inside the bus is the object of the study. Some of the conclusions from the simulations conducted as part of this project are:

- The roof hatches are very effective in ventilating fire smoke. Therefore an automatic opening of roof hatches triggered by the driver would be useful. One example when this would be of importance is if a fire breaks out inside the bus when it is travelling through a tunnel.

- The upper part of the bus will quickly be obscured in the event of a fire. This will happen even if roof hatches and doors are open. Emergency opening handles are typically found near the upper parts of the doors. They will therefore be obscured within a minute after the fire has started. In this perspective it could be a good idea to move the emergency opening handles to a lower position.

- It was found in the particular model used in this report that needle felt in the ceiling is the main route for fire propagation through the bus. Therefore a limitation of combustible material in the ceiling would slow down the overall fire propagation in the bus.

Simulations should be handled with care, however, and should definitely not be used as an alternative to experiments, rather as a complement. The reason for this is that there are many unknown parameters affecting the simulations and experiments are therefore needed in order to validate and help interpret the simulation results.
10 Appendix 1

Calculation of thermal inertia and ignition temperature of needle felt
In this section the investigation of the needle felt is presented. The theoretical background is not explained but can be found in for example reference [11].

Experimental set-up
The needle felt was tested in the Cone Calorimeter, ISO 5660-1, see Figure 97 below. Specimens of 0.1 by 0.1 m are exposed to controlled levels of radiant heating. The specimen surface is therefore heated and an external spark igniter ignites the pyrolysis gases from the specimen. The time from start of heat exposure to ignition of the sample is recorded and used in the analysis below.

Single tests were performed with irradiation levels of 5, 10, 15, 20, 30, 40, 50, and 60 kW/m². The needle felt is of type “Y9” used in reference [4] and is glued onto a laminate “Perstorp”, code “Y4”. The glue is “Bostik 87”.

Figure 97. Schematic drawing of the Cone calorimeter, ISO 5660.
Results and analysis

The experimental results are given below.

Table 22  Time to ignition, $t_{\text{ign}}$, as a function of irradiation level for the needle felt tested in the cone calorimeter.

<table>
<thead>
<tr>
<th>Heat exposure, [kW/m$^2$]</th>
<th>Time to ignition, $t_{\text{ign}}$ [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>no ignition</td>
</tr>
<tr>
<td>10</td>
<td>400</td>
</tr>
<tr>
<td>15</td>
<td>179</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>41</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>60</td>
<td>12</td>
</tr>
</tbody>
</table>

For the analysis of the results a system of three equations is solved. These equations are presented below without further explanations below. Details of the analysis are given in reference [11]. The equations are:

Equation for heat flux equilibrium at minimum heat flux:

$$\alpha_s q_{\text{min}} = h_t (T_{\text{ign}} - T_\infty) + \alpha_s \sigma (T_{\text{ign}}^4 - T_\infty^4)$$

Janssens’ equation for thermally thick materials:

$$q = q_{\text{min}} \left[ 1 + 0.73 \left( \frac{k \rho C}{h_t^2 t_{\text{ign}}} \right)^{0.55} \right]$$
Definition of effective convective coefficient:

\[
h_{\text{eff}} = \frac{\alpha_s q_{\text{min}}}{(T_{\text{ign}} - T_0)}
\]

Where
- \(\alpha_s\) is the surface absorptivity, set to 0.9,
- \(q_{\text{min}}\) is the minimum irradiation level for ignition, set to \((10+5)/2=7.5\ \text{kWm}^{-2}\).
- \(h_c\) is the convective coefficient, set to 0.013 kWm\(^{-2}\)K\(^{-1}\).
- \(T_{\text{ign}}\) is the ignition temperature,
- \(T_\infty\) is the ambient temperature,
- \(\sigma\) is the Stefan-Boltzmann constant, \(\sigma=5.67 \cdot 10^{-11}\ \text{kWm}^{-2}\text{K}^{-4}\),
- \(q\) is the irradiation level,
- \(k\) is the thermal conductivity,
- \(\rho\) is the density,
- \(C\) is the specific heat,
- \(t_{\text{ign}}\) is the time to ignition, and
- \(T_0\) is the initial temperature.

Solving for \(k\rho C\) and \(T_{\text{ign}}\) gives:

\[
\begin{align*}
k\rho C &= 7.04 \cdot 10^5 \text{ J}^2\text{m}^{-4}\text{s}^{-1}\text{K}^{-2}, \\
T_{\text{ign}} &= 257^\circ\text{C}.
\end{align*}
\]
10 References


9 http://filzfabrik.de/uk/nadelfilz.html

10 http://www.goodfellow.com/csp/active/gfMaterialInfo.csp?text=*P&MATID=ES30&material=1


12 http://www.goodfellow.com/csp/active/gfMaterialInfo.csp?text=*P&MATID=CV31&material=1


SP Technical Research Institute of Sweden develops and transfers technology for improving competitiveness and quality in industry, and for safety, conservation of resources and good environment in society as a whole. With Sweden’s widest and most sophisticated range of equipment and expertise for technical investigation, measurement, testing and certification, we perform research and development in close liaison with universities, institutes of technology and international partners.

SP is a EU-notified body and accredited test laboratory. Our headquarters are in Borås, in the west part of Sweden.