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Report RO 2001:01e

Fire in a bus on 22 July 1999 at Glumslöv, M County, Sweden

O-03/99

The report is also available on our Web site: www.havkom.se

Translated by *Tim Crosfield* from the original Swedish at the request of the Board of Accident Investigation. In case of discrepancies between the English and the Swedish texts, the Swedish text is to be considered the authoritative version.

2001-06-20 O-03/99

Swedish National Road Administration
Swedish National Rescue Services Board

Report RO 2001:01e

The Board of Accident Investigation (Statens haverikommission, SHK) has investigated a fire that occurred on 22 July 1999 in a bus with registration number GWF 576 in Glumslöv, M County, Sweden.

In accordance with section 14 of the Ordinance on the Investigation of Accidents (1990:717) the Board herewith submits a report on the investigation.

Olle Lundström Jan Mansfeld

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Report finalised 2001-06-20. English translation 20 August 2001

Vehicle: registration, type		**GWF 576**, Neoplan N128/4 Megaliner
Owner/Operator		Swebus Reseservice, Göteborg, SWEDEN
Date and time of event		22-07-1999, approx. 16.40 hrs in daylight *Note*: All times in the report in Swedish summer time (SST) = UTC + 2 hours
Place		Glumslöv, M-county, Sweden
Type of journey		Tourist traffic
Persons on board:	*Crew*	1
	Passengers	Approx. 50
Injuries to persons		None
Damage to vehicle		Extensive
Other damage		None
Driver's age, licence		42 years, licence with Swedish certification ABECDE

The Board of Accident Investigation (SHK) was notified on 23 July 1999 that fire had broken out in a bus at Glumslöv, M-county, Sweden, at about 15.30 hrs on 22 July.

The accident has been investigated by SHK represented by Olle Lundström, Chairman and Jan Mansfeld, Chief Technical Investigator.

The Board was assisted by Hans Carlbom as technical fire expert.

The investigation was followed by the Swedish National Road Administration represented by Lars Carlhäll and by the Swedish National Rescue Services Board represented by Klas Helge.

1 FACTUAL INFORMATION

1.1 History of the occurrence

Swebus Sverige AB ran regular timetabled services between Malmö and Göteborg, and other places. On 22 July 1999 one of the company's buses, a double-decker with registration number GWF 576 was en route for Malmö. The driver and 53 passengers were on board. At the entrance to the Knutpunkten bus terminal in Helsingborg the driver lowered the bus chassis to be able to enter, the height limit being 4.25 metres. When the chassis was lowered the steering became heavy, which is normal. He stopped at the bus stop, where some passengers alighted. After leaving Knutpunkten he again raised the chassis with certain difficulty, but the heaviness in the steering persisted. He also thought he smelt a kind of "industrial" smell. He stopped after a few kilometres and rang to Swebus traffic control. He did not consider the bus should be driven further but after discussing with traffic control he decided to attempt to drive on to Malmö.

He drove up onto the motorway. After about 15 km a passenger said he could smell smoke and in the rear vision mirror he indeed saw smoke. He immediately drove onto the shoulder and stopped. However, he left a gap to the motorway safety rail to make alighting possible. He turned on the bus warning lights, alighted and went to check the engine compartment in the rear part of the bus. Through the engine cover grating he saw limited flames on the left side of the bus. He went back to the driver's seat and turned off the engine. He requested the passengers to get out immediately and stand on the road shoulder in front of the bus. He then notified the emergency services SOS Alarm via emergency services number 112. He next took the bus fire extinguisher and tried unsuccessfully to put out the flames by spraying them through the engine cover grating. Meanwhile some passengers started to take out their luggage. He urged them to stop, for their own safety. However he took out one passenger's rucksack, which was said to contain petrol.

The smoke became denser and finally meant that motorists bound for Malmö did not dare to drive past the bus.

The Landskrona rescue service arrived about 10 minutes after the alarm and began to put out the fire in the engine compartment. At the same time police and ambulance arrived on the scene. A while later reinforcements arrived from the Helsingborg fire department and attacked the fire inside the bus. The whole fire-extinguishing operation and subsequent rescue work took about two hours.

The powerful development of smoke caused the police to stop the traffic in both directions until the smoke had died down sufficiently.

After consultation with the ambulance staff it was decided that the driver should be taken to Malmö General Hospital. There he was admitted for observation and was able to leave the hospital the next day.

The passengers continued their journey with a replacement bus that had been requisitioned.

1.2 Injuries to persons

Apart from the check on whether the driver had incurred smoke injuries, none of those involved needed to seek medical help.

1.3 The fire

The fire started in the engine compartment near a turbocharger unit on the left-hand side. From there the fire entered the luggage compartment. It

spread first over the surface of the luggage, then penetrating it more and more. From the luggage compartment the fire continued to the lavatory area, subsequently making its way out through the doorway to the passenger compartment, where the flames and the hot smoke gases flowed up through the rear stairwell. The seats near the upper part of the stairs were ignited. The roof of the bus was burned through. The main part of the heat released was then ventilated that way.

1.4 The rescue services operation

Notification of the accident reached SOS Alarm at 15.57 hrs and was immediately passed on to the Landskrona rescue service. The first rescue vehicle left the station one minute later and arrived at the scene of the accident at 16.05 hrs. One hose was run to the rear left side of the bus and one to the right, whereupon fire fighting in the engine compartment was started. Some 15 minutes later a reinforcement arrived from the Helsingborg fire service. Smoke divers were now able to enter the bus and attack the fire which had taken a firm hold on the interior fittings. An unsuccessful attempt had previously been made to smash the upper deck front window. The extinction of the fire and the ensuing measures took a total of about two hours. The fire was difficult to put out, particularly since the luggage had been tightly stowed and there were several fairly small recesses for heating and engine cooling units with expansion vessels.

The police and ambulance services arrived at the same time as the Landskrona rescue service. The large production of smoke also affected the northbound lanes of the motorway to such an extent that the police decided to stop all traffic until the smoke had died down sufficiently.

The passengers, who had stood together in front of the bus, were helped by police and ambulance personnel and given temporary shelter from wind and rain in the emergency vehicles. A substitute bus had been called up and arrived after about an hour. The passengers were taken to their respective destinations in this bus.

1.5 Damage to the bus

Extensive.

1.6 Other damage

Much of the luggage in the luggage compartment of the bus was destroyed.

1.7 The driver

At the time the driver was aged 42 and held the necessary ABECDE driving licence. He had been driving buses for 21 years.

1.8 The vehicle

General

Owner:	Swebus Reseservice AB
Make	Neoplan N128/4 Megaliner
Chassis number	401282WSP26813
Year of manufacture	1998
Distance driven	287 148 km as per 20-07-1999

The bus was a double-decker with room for 86 passengers, of whom 64 on the upper deck. It was 15 metres long, 2.44 metres broad and 4.20 metres high. Its service weight was 21,210 kg and total weight 28,670 kg. It was

first registered on 1 December 1997 and the latest road safety test was on 9 December 1998.

The upper deck was only for passengers, and was reached by two staircases. The lower deck, reckoning from the front, consisted of the driver's area, the passenger compartment, lavatory, luggage compartment, engine compartment and spaces for the air-conditioning unit. A smallish portion of the engine compartment was under the rear part of the luggage compartment.

The bus had three doors, all on the right-hand side. The front and middle ones were for ascending and alighting and the rear for loading and unloading luggage.

The bus chassis could be raised and lowered.

Throughout the description of the bus 'right' and 'left' refer to the direction of travel.

To gain a reliable picture of what the bus looked like before the fire SHK was able to examine a bus of the same design. This bus had registration number GWF 586 and is referred to in what follows as the twin bus.

The body

Like on many other new buses, hatches and portions of the outer walls were in fibreglass-reinforced plastic. This material has relatively low fire resistance. In a fire the plastic disappears, leaving a shapeless tangle of fibrous material. Several of the inner partition walls were also made of similar material.

The interior walls of the bus were surfaced with synthetic textile fibre bonded direct onto the base material.

The engine compartment

In the description of the engine compartment the twin bus was used since the fire damage precluded determining how the various parts were arranged.

The bus had a Mercedes Benz turbocharged V8 diesel engine of basic type 400 with twin turbochargers. The cylinders V-shape formed an angle of 45 degrees. The engine was situated far back with the crankshaft longitudinally to the bus. This engine was originally intended as an industrial power unit but had been adapted for vehicles. Under heavy engine load the turbocharger fan housing reaches a temperature of several hundred degrees. As protection against dangerous heat radiation a shield plate had been fixed over this.

Combustion air to the engine was drawn in through a grid behind the rearmost bus axle on the left-hand side, where the air filter was located. The cylindrical air cleaner had a diameter of approx. 50 cm and a length of approx 60 cm, and was placed horizontally at right angles to the longitudinal axis of the bus. An outer net mantle contained the filter that cleaned the combustion air for the engine. The main part of the air cleaner was a space. The engine requires a great deal of air, so that a large filter area is needed to cope with the air supply.

Immediately above the air cleaner space and to the left was a fairly small space with a grating to the open air. This admitted cooling air to the air-conditioning unit condenser, and it also contained the engine coolant tank. The engine radiator was situated in the engine compartment to the far left. Behind the radiator were two large fans, one above the other, which blew air through the radiator unit.

Exhaust gases from the left half of the engine were led from the manifold along a pipe under the engine, while from the right half of the engine the

pipe from the manifold was bent forwards and diagonally downwards to the right. The two exhaust pipes joined at the silencer. The exhaust pipe outlet was under the engine on the right-hand side of the bus.

The fuel tank was placed on the right-hand side of the bus about a metre behind the front wheel. The fuel lines were of approved type. The engine was provided with fuel via an injection pump, driven directly from the camshaft. The upper portion of the engine was, as already mentioned, a V formed by the rows of cylinders and their heads. The pump was located in this V, sloped to be parallel with the right-hand cylinders. The pump was cooled with fuel, giving a large flow even in the return lines from the cylinders. The "dish" formed by the cylinder V had a capacity of 3 litres of fluid.

This type of bus is steered by two linked, divided front axles. The more forward front axle is controlled via a servo which receives hydraulic pressure from a pump driven from the engine transmission. The more backward front axle receives its servo pressure from a pump driven by the propeller shaft. In the event of a fault on the front axle servo the propeller-shaft driven back axle servo can act as an emergency steering system. The steering geometry presupposes the bus being driven at normal height. When the body is lowered or raised the driver senses that the steering becomes heavy or unsteady, respectively.

The front axle steering servo received its oil under pressure through the lines and the hose running from a servo pump on the engine block to the steering unit. This direct-drive, hydraulic fluid pump was placed on the front of the engine in the direction of travel, immediately to the left of the centre-line of the bus. From the pump, hydraulic fluid was led through a line fixed with clips to a sheet-steel bracket, the foot of which was formed by bending the steel to a right angle. There were two of these brackets, both attached to the shield plate over the turbochargers, one to its front and the other further back. Somewhat lower there was a changeover coupling where the line changed to a hose.

For the transition from line to hose a shrink coupling was used. A hose tail was placed in the hose, and a tool was used to compress a hose cuff round the outside of the hose and against the tail, forming a sealed unit. At its other end the hose was fixed in a corresponding manner to the line connecting the hydraulic pump and the steering unit. The line was fixed to the chassis.

To hold the hydraulic fluid hose in position a clip around it was fixed to the above-mentioned bracket on the shield plate with a simple screw connection.

The bus chassis was practically smooth as far rearwards as the engine. The type is supplied with covering hatches under the engine compartment but these hatches were lacking on this bus and the twin bus. It happens that these are not replaced after an overhaul. This means that the air swirled in under the bus when it is in motion is taken up into the engine compartment, contributing to the cooling.

The engine compartment was separated from the luggage compartment by mineral wool-insulated partition walls. On the engine compartment side the mineral wool was covered in aluminium foil. The mineral wool was of the rock wool type with a high softening temperature. The material has both fire-resistant and soundproofing properties.

There was no common partition wall between the engine compartment and the upper passenger deck. The space above the engine compartment contained the vehicle's air conditioning plant

There was no fire alarm in the engine room in this bus type.

The luggage compartment

In addition to the door on the right-hand side, the luggage compartment was accessible via three fairly large hatches on the left-hand side.

For checks and simple maintenance of the forward portion of the engine there were four hatches in the luggage compartment floor. Three of these were furthest back in a raised part of the floor. The difference in levels was covered by a sloping surface. In this there was a hatch measuring 285 x 810 mm. All the hatches were fireproofed and had aluminium foil on the engine compartment side. To retain the hatches in place each had one simple bolt at each end. The bolt was a stepped, 5 mm steel strip with two 90-degree bends. It was retained between two nuts on a bolt passing through the hatch. The head of the bolt was on the luggage compartment side and had a straight notch suitable for an ordinary screwdriver. The bolt was completely exposed to ambient air in the engine compartment.

On the right side of the bus next to the engine compartment there was a small space between the luggage compartment door and engine compartment. This housed a heating unit with an oil burner and a water pump for circulating the water to radiators inside the bus. There were also radiators in the luggage compartment.

The luggage compartment was separated from the passenger compartment by a thin, fireproofed wall and from the lavatory by a wall of corresponding material. The latter wall, however, contained a fairly large plastic hatch.

The lavatory

The lavatory floor, walls and ceiling formed one unit cast in fibreglass-reinforced plastic. Apart from the lavatory pan there was a washbasin. To connect the basin to a water tank and to facilitate technical maintenance the lavatory unit was accessible through the hatch mentioned earlier, which was opened from the luggage compartment. This hatch was of thin moulded plastic. The material was only a few millimetres thick and the plastic had a low softening temperature, but through its design the hatch was sufficiently stable at normal temperatures. For emptying the lavatory there was another hatch close to the door to the luggage compartment.

The door between the toilet and the passenger compartment was of plywood, faced with the same textile as the other walls in the bus. It was hung to the left, thus opening from the lavatory to the right. Since it opened onto the rear stairs to the upper deck it was specially designed to open fully although it crossed over the stair immediately over threshold level.

The ventilation plant

The bus had an air-conditioning plant that supplied the passenger compartment with treated outside air. The air was taken in through two gratings, one on each side of the bus, and led through the respective units where it was pre-warmed or cooled. It was then led further to the passenger compartments via longitudinal ducts to nozzles in control panels over each double seat.

Both units for treating the air were sited above the engine room and below the upper-deck floor level. The condenser was placed inside the gratings to the rear of the bus just above the engine hatch. The air for the condensor was drawn in through the gratings, which were placed at the same height in the left and right side of the bus furthest back. The gratings above the engine hatch formed outlets for the air that had been through the condenser. For air extraction there were six fans immediately inside the gratings.

Used air from the passenger compartments was removed through gratings forward in the bus. The wind caused by the bus speed was used to create suction controlled by a damper.

The driver's area was served by its own fan unit, with air drawn in from the front.

The luggage compartment was supplied with air through two gratings in each of its rear corners. From the luggage compartment the air was removed through a short duct some decimetres from the left rear corner. The exchange of air to the luggage compartment was by natural draught.

1.9 Weather conditions

The weather was rainy and windy.

1.10 The site of the accident and the vehicle wreck

1.10.1 The site of the accident

The accident occurred on the E4/E20 motorway at Glumslöv, approximately 10 km north-west of Landskrona.

1.10.2 The vehicle wreck

The damage was extensive. The engine was totally destroyed and the engine compartment entirely burned out. The upper-deck fittings were largely destroyed by fire and smoke. The luggage compartment and the lavatory were entirely damaged by the fire. The lower passenger compartment was relatively unharmed.

1.11 Survival aspects

All those on board the bus were able to evacuate before any danger to their lives arose.

1.12 Tests and research

1.12.1 The fire damage

Introduction

After the accident the bus was towed to the Swebus workshop at Kungälv, where the investigation was carried out. SHK first noted the external damage to the bus. Then the upper deck was gone over. Here the fire damage was markedly well localised around the rear stairwell. In the lower-deck passenger compartment there was fire damage only around the lavatory. The luggage compartment was examined thoroughly. Next the engine compartment walls and ceiling. Lastly the engine was lifted out and examined.

Body and passenger compartments

From the outside it was noted that the bus roof was damaged by heat over somewhat more than a quarter of its surface. It had been burned through immediately forward of the rear stairwell. The middle of the three luggage compartment hatches on the left-hand side of the bus was completely burned through. The grating immediately behind the rear luggage com-

partment hatch was severely affected by heat from inside. The engine room hatch had been entirely burned away. The window in the rear wall of the bus was missing. On the upper deck three of the large windows on the left and four on the right were missing. In the upper deck right-hand windscreen there was an impact mark.

At its largest, the extensive area burned through in the roof was 1.62 metres longitudinally and 1.00 metres wide. Around its edges part of the fibreglass reinforcement hung down like a cloth from a table.

Eighteen of the 64 seats in the upper deck were entirely destroyed. Of six of these only the cleanly-burned steel frames remained. Nineteen of the 46 remaining seats had more minor damage in the form of burnt stuffing, burned textile covering and blackened cloth. The majority of the other seats were only covered with soot or had been damaged by melted plastic. Walls and ceilings around the damaged seats had sustained various forms of damage depending on the distance to the centre of the fire. Walls and ceiling around the 27 undamaged bus seats exhibited no real fire damage, only limited smoke damage.

The luggage racks, or rather hat racks, were of metal with complete bottom parts and stout doors. To the front on the upper deck a hole was made in the rack since even where the rack had been subjected to very high temperatures it had not been appreciably deformed. The material was very robust and would presumably resist relatively severe strains.

The seats on the lower deck had not sustained any fire damage. There were, however, fairly small quantities of loose soot particles on some seats. On the outside of the lavatory door there were still pieces of the textile covering. The portion of interior wall closest to the lavatory was remarkably unaffected by the fire. The rest of the stairwell was severely damaged by the fire, however.

To determine whether the ventilation system had contributed to the spread of the fire or further spread of fire smoke, the air ducts were examined. It was soon evident that the ducts were quite clean on the inside apart from a few centimetres from the places where they had been burned through from the outside or demolished by failure of their supporting elements.

The lavatory

Inside the lavatory it was noted that the door had been subjected to severe fire effects on its inside and had become warped both at its upper edge and its lower. In addition there were two large holes in the wall abutting the luggage compartment. One was through the hatchway. Parts of the melted-down hatch were found in the fire debris on the compartment floor. The other hole was in the wall at right angles to the former, also abutting the luggage compartment. In addition, remains of bus fittings above the lavatory pan had fallen down. There were also fibre remains from the reinforcement in the compartment.

During examination of the twin bus it was noted that the lavatory door was so arranged that it covered the whole opening but did not enter the frame, the bolt being fastened on the outside of the frame. However the door could be shut properly with negligible force.

The luggage compartment

Examination of the luggage compartment revealed first a quantity of broken glass from the windows damaged in the fire. The glass had been poured in when the roadway was being cleared up. On removal of the glass it was noted that a large part of the luggage had been damaged. Among the

remains, half-burnt shoes, suitcases and rucksacks were found. In certain cases only scraps of clothing remained. There had been much synthetic material which had melted into lumps of different forms. Parts of the fittings had also melted down into lumps.

In addition there were considerable remains of fibre. In structure and form they resembled chunks of wood-wool, except that the material in the fibre pulp was non-combustible. When these remains had been removed the luggage compartment floor proved to be covered with a rubber-based synthetic material. Portions of this matting were burnt out, but a large part had been protected from the flames by the luggage. The hatches giving access to the engine compartment were largely intact. In the hatch immediately over the turbo fan, the screw head of the bolt was rusty. Closer investigation showed that the immediate vicinity of the bolt screw was burned away and that the whole bolt was hanging loose. It was also noted that the matting close to the bolt was burned away. The luggage in this part of the compartment was particularly badly damaged. There were no other burns-through between the engine compartment and the luggage compartment.

The wall between the luggage compartment and the passenger compartment was burned through at one place, giving an opening over the rearmost part of the left-hand, lower-deck luggage rack. There was however no soot marks on the ceiling. On the other hand, the edge of the hole was blackened with soot all round. Just under the luggage rack there was a small, round 7-8 mm hole. However there were no traces of soot round the hole on the passenger side.

The engine compartment

To begin with the motor compartment was examined with the engine still in position. It was immediately noted that the compartment had been subjected to very severe fire. The damage was worst on the left-hand side.

The rear engine hatch had been burned away.

The hottest area had been round the left turbocharger unit. The right unit had not been equally strongly heated.

For examination of the twin bus the engine compartment hatch over the left turbo was removed so that the path of the hydraulic hose of the steering servo line could be seen. In the fire-damaged bus the hose was damaged. In the twin bus, too, the fastening point of the hydraulic line to the shield plate had started to fail in the same way, i.e. the steel line with the hose connection had been in contact with, and repeatedly struck the edge of, the shield plate. This had been going on for some time so that wear damage had developed on shield and connection without either so far failing.

On the fire-damaged bus, moreover, the clip to one of the brackets had parted so that the hose hung loose, being caused to swing when the bus was in motion. There were traces of wear at the fastening point, indicating that the hose had frequently moved in this fashion. Since the hose was somewhat too short it did not enter the connection straight on, but formed an angle immediately with the connection. This arrangement of the hose, which according to the hose manufacturer is incorrect since it leads to a lateral strain at the entrance to the connection, caused a risk of leakage.

The placing of the hydraulic hose in the immediate vicinity of the turbocharger unit caused it to age more quickly than if it had been placed in a cooler position. In addition a fire-blackened pulp on the hose formed a straight trace along its underside.

In both buses the hydraulic hose was not adequate for the natural movements of the engine, being too short. It was therefore unable to take up the oscillations between engine and chassis without being damaged. No

account had been taken of the movements arising through changes in the hydraulic fluid pressure. In the twin bus the engine had jerked the hose sufficiently to cause slight leakage of hydraulic fluid at the point where the hose joined the metal line on the chassis. The fault on the twin bus was rectified immediately by the workshop.

On the burnt bus, the hydraulic hose, which is arranged to allow movement between the steel line from the engine servo pump and the steel line on the left-hand side of the chassis, had come loose from its fastening between the hose tail and the shrink coupling that formed its connection to the line on the engine side. In the twin bus, the hose had started to work its way out of the shrink coupling. Leakage there may in terms of fire safety normally constitute a fairly small fire risk.

On the burnt bus dripping hydraulic fluid from the leak landed on the hot shield plate over the turbo fan.

During the investigation it was also noted that the steel line from the servo pump on the burnt bus was loose at its fastening to the servo pump, and that the connection was not a full seal. A steel clip serving to retain the other end of the steel line on the left-hand turbo shield plate had failed, allowing the line to move. The engine showed traces of burnt fluid around the servo pump and on the engine block.

The left-hand locking bolt for the engine compartment hatch to the luggage compartment had been very hot, and the area around the locking device was burnt through. The other locking devices had been very hot but there was no burn-through around these.

Regarding the electrical system, a number of cables were so long that they had been shortened by folding the excess length and fastening it together with a plastic strip. However the electrical system showed no damage that can have caused the fire, but the insulation had started to burn.

The fuel lines had largely been burned away.

To check the entire engine compartment the engine was lifted out. To its left were the two cooling fans and their radiators. To its right was the compressor for the air-conditioning plant.

Other auxiliary units were positioned either on the engine or in other parts of the engine compartment.

The area nearest the turbo fan on the left-hand row of cylinders had sustained the deepest fire damage. Following colour changes showed that the damage had its centre in the forward left-hand corner. Here, apart from the turbo fan, there are only components of the engine cooling system. The temperature had been so high that the insulation around the electrical cables had been burned away.

The upper, forward part of the grating to the compartment containing the coolant tank had been entirely stripped of its paint, and deformed, but not burned. The upper part of the grating was blackened, as was the lower forward corner. The paint in the rear lower corner was mainly undamaged. The colour change on the grating proved to be because the tank cap and associated piece of tube had come loose when the solder melted and ran. The freed opening was in the middle of the discoloured surface. The overheated coolant with its added anti-freeze had been blown out by steam pressure formed in the tank heated by the fire. The powerful reaction was thus a consequence of the fire. The most common anti-freeze preparations contain high-grade (with many carbon atoms) alcohols. Even though the highest dilution is 50%, the mixture is inflammable. The deformed grating suggests that it had been exposed to high temperatures. There were no other traces of violent burning in the vicinity. This violent combustion did not otherwise affect the course of the fire.

Six aluminium fans placed in the rear wall of the bus were entirely melted down.

Even taking the fire into account, the engine compartment of the burnt bus appeared unusually dirty. This appeared largely to consist of road dust blown up and bound in several places by thin oil films from wet seals. Examination of the twin bus showed corresponding circumstances.

1.12.2 Fire resistance testing of the bus seats

Since the fire developed very rapidly with comprehensive damage as a result, SHK decided to find out whether, and if so to what extent, the bus fittings had such characteristics as to have contributed to the rapid ignition.

During the past three decades many fire resistance testing methods have been used in the attempt to classify material. These methods were originally developed on the basis of experience of fires in wood and wood-based material and products. The methods do not meet fundamental requirements as to giving information on properties or phenomena that are functionally and distinctly defined. In the use of new types of material – particularly plastics – they have often proved to give incomplete information and not infrequently erroneous base data for assessing the behaviour of materials and surface layers under real fire conditions. As early as the 1960s comparative trials were conducted in six European fire laboratories in the then West Germany, Belgium, Denmark, France, Holland and England in cooperation with ISO (International Standardization Organisation). All the test results, covering 24 materials, were then compiled and there proved to be a remarkably large spread in these. The surface material considered by one country's test standards to be the safest was ranked as the most dangerous of all 24 materials according to another country's.

Within Europe a standardised method for testing upholstered furniture was worked out later on. This was intended to apply jointly in the participating countries. This, however, did not come about, largely for reasons of commercial policy.

SHK used the latter method. The test was carried out by the National Swedish Testing and Research Institute in Borås.

The test object was an undamaged double seat from the burnt bus. This was placed on a scale platform and one half was ignited in the seat and back cushion using a gas burner with a 30 kW output. The ignition sequence lasted two minutes. All combustion gases formed during combustion were collected in a hood placed over the test object. By measuring the consumption of oxygen during the fire its heat output was calculated. The smoke production was measured using a lamp (white light) and a photocell mounted in the flue downstream from the hood.

The test report shows that the maximum heat effect developed was 1 052 kW. Total heat energy released during the test was 333 megajoules, i.e. million joules. The average effective heat of combustion was 24.7 MJ/kg. Maximum heat radiation was 47 kW/m^2.

The measured heat effect from the fire gives information on the chances people have of evacuating and on the risk of further spreading of a fire. A heat effect of approx. 1000 kW suffices to cause flames in a fairly small room (approx. 10 m^2 floor) with the door open. In the present test this effect was reached after 9 minutes and the maximum after a further 5. This means that one double seat of this type would be enough to set a bus of corresponding size on fire even if there were no other combustible material. A real bus fire with these seats would be brought under control by ventilation quite quickly; in other words the fire would at a maximum be as large as the availability of oxygen permits. A bus with large glass surfaces that

break under heat allows good availability of oxygen, and a considerable size of fire can thus be expected.

When an area catches fire, i.e. the heat becomes so great that radiation energy from fire gases ignites objects in the area (often explosively), the point at which nobody survives has been passed: A bus in flames has passed the point at which people lose their lives. It has earlier been found that evacuation from a small room with an open door can take place only with a maximum heat effect of 200 kW – 400 kW. In the present test a heat effect of 200 kW was reached after about 4 minutes. After about the same time the fire will rapidly increase, since the seats adjacent to the burning one can be expected to be ignited by the heat radiated.

1.13 The company's organisation and management

1.13.1 General

Swebus 'core activity is local and regional timetabled bus traffic on behalf of the country's traffic principals. The latter are owned by county councils and municipalities, basically one principal per county. Swebus operates approximately 2 600 buses in this type of work in Sweden, hence having about 30% of the market. In addition the company runs a national express bus network, Swebus Express and hire and tourist traffic. With about 6 000 employees in Sweden and Finland and a total of about 3 000 buses, the company is a market leader in Sweden. Swebus was at the time of the accident owned by Stagecoach, a traffic company with headquarters in Scotland.

1.13.2 Maintenance routines

Every bus has a depot with workshop facilities. The workshop manager is responsible for periodic maintenance of the buses according to company routines. The company's technical director is responsible for the contents of these routines.

2 ANALYSIS

2.1 Cause of the fire

When a bus is in motion the engine vibrates and moves as designed. This means that hoses and other connections to the engine must be so designed and dimensioned that they can absorb these movements without being damaged.

In the investigated bus, as in the twin bus, it was noted that the hydraulic hose for the steering servo was too short and could not take up engine movements. When the engine moved a maximum to its right, the hose was subjected to strong tension and jerks. These movements were so strong that the steel clip retaining the line against the shield plate eventually failed, whereupon the line started to vibrate. The weight of the hydraulic hose and the movements of the engine caused the steel line to twist about its connection to the servo pump and the nut finally became unscrewed, allowing fluid to leak through the connection.

The connection of the hydraulic hose to the shrink coupling was also subjected to unintentional jerks and tensions. For this reason it started to slowly creep out of its shrink fastening to the hose bracket, eventually

causing a further leak. The leak became larger and larger and finally formed a jet.

Both leaks were initially small and the fairly small quantities did not strike the hottest part of the engine. When the fluid was heated by the engine it was vaporised, as indicated by the fact that parts of the engine were discoloured by dried fluid. That the fluid was initially vaporised may also explain why the leak was not discovered at an earlier stage during the bus 'operation.

When the leakage increased, fluid finally spurted out under pressure from the servo pump. It was atomised and struck the hottest part of the engine, 450–750 °C. It was ignited, then functioning as a flamethrower in the inner left-hand portion of the engine compartment where heat developed very rapidly and the fire damage was concentrated.

When after the stop in Helsingborg the driver was able to raise the bus chassis to normal height, the bus continued, abnormally, to be heavy-steered. It is probable that the hydraulic hose had already been pulled loose from its fastening and that a continuous leak had started.

2.2 The course of the fire

Note first that the investigation demonstrated no other source of ignition for the fire in the luggage compartment than the engine fire. Initial uncertainties as to whether there could have been self-ignition in some material or leaking fumes from e.g. spirit stoves, bottles of petrol or the like have, following scrutiny of the compartment contents, been ruled out.

Observation of the fire damage outside the engine compartment shows the fire to have had the following course.

When the fire in the engine compartment became intense, an area in a hatch to the luggage compartment was burned through, igniting portions of the luggage. The fire intensity there was initially fairly low and the fire may have continued for some minutes. When it had become sufficiently violent – presumably after the addition of oxygen when the driver opened the luggage doors to take out the petrol container and when the left-hand luggage hatch was burned away – the large plastic hatch in the wall to the lavatory compartment was burned away and the fire took hold there. The main damage was noted in the area above the lavatory pan and on the door. It was much burnt on the inside. This may indicate, as noted during inspection of the twin bus, that it was not fully shut but only pushed to, very likely when the driver braked and stopped by the side of the road. It was probably at this stage, possibly somewhat later, that the fire entered the lavatory.

If initially the door was only pushed to, pressure from the fire, which gained its main addition of oxygen from the rear, soon caused the door to open, supplying the fire with more additional oxygen. Flames and the main part of the accumulated smoke gases now spread up through the rear stairs to the upper deck. This phase of the fire spread was probably rapid. The seats in the vicinity of the stairs were ignited and the bus ceiling burned through. Further spread of the fire was stopped through the efforts of the rescue services.

2.3 The rescue operation

The Landskrona rescue services and the police arrived quickly at the scene of the accident. Apart from the thick, billowing smoke, flames were shoot-

ing out through the rear left-hand windows of the bus. It was decided however to begin by extinguishing the fire in the engine compartment. When the Helsingborg rescue service arrived it was possible to attack the interior fire also.

As far as SHK can judge the rescue service operation was as rapid and correct as could be desired. The low degree of secondary damage in the form of water damage also indicates that the use of means of extinction was well judged. The only query concerns the attempt to break the front window in the upper deck. The attempt failed because the front window-panes are made of laminated glass, i.e. double panes with a layer of plastic in between. This material is tough and very hard to break. If it becomes necessary to enter a similar vehicle rapidly through a window, a side window should be used.

The police decision to close the road to all traffic was naturally justified for reasons of safety.

SHK judges the driver's action as very good. He appears to have acted calmly and methodically. By removing the container of petrol, however, he appears to have exposed himself to some danger. His decision to evacuate the passengers quickly and his instructions to them to leave the luggage in the bus contributed to the fact that no passengers were injured.

The passengers were cared for as well as the circumstances allowed.

2.4. Safety aspects

To protect both passengers and the rest of the bus from the consequences of a fire in the engine compartment, the wall to the luggage compartment was designed to resist fire for a certain time. However, the resistance of the wall was reduced by the uninsulated steel screw in the bolt of one wall hatch. If the bolt had been fire-proof the fire would not have reached into the luggage compartment as relatively quickly as it did. Concerning the further spread of the fire, the same may be said of the plastic hatch into the lavatory compartment, which should have been of fireproof material.

In an earlier report on a bus fire (Report RO 2000:1) SHK noted that since the engine of a modern bus is sited far from the driver's area, there is need for an automatic fire alarm installation in the engine compartment. In view of the course of events in the present investigation the luggage compartment should also be equipped with such an installation.

Reports from the bus industry and insurance companies show that bus fires are relatively frequent and that the tendency is increasing, particularly in fairly new buses. Most affected are tourist and long-distance buses. The fires start most often in or near the engine compartment.

Anyone dealing with a fully developed fire in an engine compartment may be subjected to great danger owing to the risk of a rapid flame-up. The first to take action is most often the bus-driver. This suggests that the engine compartments in modern buses should be equipped with extinguishers. This is particularly important for long-distance buses since they are often at great distances from the local rescue service. An extinguisher can be started either automatically or manually by the driver following a signal on the instrument panel.

It is noted that the National Road Administration is currently drafting new rules for test surveys of buses for enhanced fire protection.

The investigated bus had two roof hatches, but there are similar buses without roof hatches. A roof hatch can be used as an emergency exit if the bus overturns on its right side, e.g. after driving into the ditch as happened in a bus accident at Fjärdhundra in November 1998 with an ensuing fire.

That bus had no roof hatch. Representatives of the bus industry have represented to SHK that youths have misused the roof hatches by opening them and sticking out their heads, which can be catastrophic when passing under viaducts and similar erections. SHK considers, however, that the presence of roof hatches may constitute a safety-raising factor. The possibilities of roof hatches operated only from the driver's area should therefore be considered. However it must also be possible to open them from the outside.

To be able to get out of a bus quickly by breaking windows, buses are equipped with a number of glass-hammers. According to the bus industry it often happens that these are stolen even though they are secured with wires. It should also be considered how this nuisance can be overcome.

In the final report mentioned above SHK made a recommendation to the National Road Administration regarding fire detection, fire extinction and emergency evacuation. For this reason SHK finds no reason to make any further recommendation in the present report.

In this connection, SHK considers that the soiling in the engine compartments of the investigated bus and the twin bus should be commented upon. The soiling was more extensive than that noted on other bus types. Since these two buses lacked cover plates under the rearward-placed engine, road dust and other material could swirl up in the air under the bus and enter the engine compartment. These particles could then mix with any spilt oil, becoming bound, which entails a further capacity to suck up oil. A collection of any size of such a mixture on the V-shaped upper part of the engine may contribute to the worsening of any fire in the engine compartment. There may be a need to check the engine compartment in buses without cover plates more frequently than is necessary for other buses.

3 CONCLUSIONS

3.1 Findings

a) The driver was qualified to drive the bus.
b) The bus complied with vehicle regulations in force.
c) The hydraulic hose in the engine compartment was too short.
d) Owing to engine vibrations, there eventually arose fluid leakage at both hose connections.
e) The fluid was ignited by hot engine parts.
f) An area around a fastening bolt in a hatch to the luggage compartment was burned away
g) The luggage ignited.
h) The fire spread through, among other things, a melted plastic hatch via the lavatory compartment and the rear stairwell to the upper deck of the bus.
i) The evacuation of the passengers was well managed.
j) The rescue services operation and the police operation are judged to have been good.

3.2 Causes

The fire was caused by fluid leakage from a hydraulic hose i the engine compartment. Contributing to the further course of events was the fact that the material in a locking bolt into the luggage compartment and a hatch into the lavatory area had no fire-resistant capacity.

4 RECOMMENDATIONS

None.