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Report RO 2000:01e

Fire in a bus on 25 January 1999 at Äskebacka, O County, Sweden

O-01/99

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.

2000-12-19 O-01/99

Swedish National Road Administration

Report RO 2000:01e

The Board of Accident Investigation (Statens haverikommission, SHK) has investigated a fire that occurred on 25 January 1999 in a bus with registration number HPX 680 in Äskebacka, O County, Sweden.

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

The Board will be grateful to receive, by 30 June 2001 at the latest, particulars of how the recommendation included in this report is being followed up.

S-E Sigfridsson Jan Mansfeld

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Report finalised 2000-12-19. English translation 15 February 2001

Vehicle: registration, type		HPX 680, Volvo Carrus B 10M 70-B
Owner/Operator		Lysekils Taxi Trafik Aktiebolag, Rosvikstorg, SE-453 30 LYSEKIL, SWEDEN
Date and time of event		25-01-1999, approx. 17.00 hrs in darkness *Note*: All times in the report in Swedish normal time (SNT) = UTC + 1 hour
Place		Äskebacka, O county, Sweden,
Type of traffic		Scheduled passenger traffic
Persons on board:	*Driver*	1
	passengers	25
Injuries to persons		None
Damage to vehicle		Total wreck
Other damage		None
Driver's age, licence		59 years, licence with Swedish certification ABECEDE

The Board of Accident Investigation (SHK) was notified on 2 February 1999 that fire had broken out in a bus at Äskebacka, O county, Sweden, shortly after 17.00 hrs on 25 January.

The incident has been investigated by SHK represented by Sven-Erik Sigfridsson, 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.

SHK investigates accidents and incidents with regard to safety. The sole objective of the investigations is the prevention of similar occurrences in the future. It is not the purpose of this activity to apportion blame or liability.

SUMMARY

At 15.25 hrs on 25 January 1999 the driver started for the scheduled trip from Göteborg to Lysekil. When he stopped at Munkeröd to set down passengers he saw smoke coming from the engine cover on the right-hand side. He crawled under the bus to see if something had had happened but could not discover anything abnormal.

During the journey he contacted, among other places, a workshop to get advice. It was decided that he would continue to Ljungskile. On arrival there the driver turned off the engine and carried out a further check. He saw no smoke. He made a further check in Uddevalla without seeing anything unusual and therefore continued towards Lysekil.

Shortly after 17.00 hrs he was approaching the Äskebacka stop where he was to set down passengers through the rear door. When he opened the rear door he distinctly smelt an acrid smell. Suddenly the engine stopped and all the dashboard lamps lit up including the fire alarm lamp. He restarted the engine which, however, stopped again after a second or so. In his rear view mirror he saw smoke pouring from the side cover beside the engine. He decided to evacuate the bus. However, the door opening control at his seat was not working, and he accordingly opened the front door with

the emergency opening control. When he had evacuated the passengers and noted flames under the engine compartment he re-entered the bus to check that nobody was still in inside. As he passed the engine compartment on his return he heard a loud explosion from it. He hurried out. Once out he saw that the fire had broken through the floor in the passenger compartment over the engine. A minute or so later the whole bus was on fire.

The occurrence was caused by a foreign body damaging the high-pressure fuel delivery pipes in the engine of the bus.

Contributing to the consequences of the initial engine fire was the inadequacy of the fire detection and extinguishing equipment.

Recommendations

The Swedish National Road Administration is recommended to seek

- the promulgation of equipment regulations for buses regarding fire detection, fire extinction and emergency evacuation (RO 2000:01R1).

1 FACTUAL INFORMATION

1.1 History of the occurrence

At about 15.00 hrs on 25 January 1999 the driver was with his bus at the Nils Ericsson Terminal in Göteborg. He noted an acrid smell around the buses at the terminal. At 15.25 hrs he started his scheduled trip to Lysekil. At about 16.00 hrs he stopped at Munkeröd to set down passengers. He then saw that smoke was coming from the engine cover on the right-hand side. He crept under the bus to see if anything had happened but could not detect anything abnormal. He concluded that the smoke had been caused by water splashing up from the road and evaporating.

During the journey he contacted a workshop among other places to get advice. It was decided– partly because no change could be detected in the performance of the bus – that he would continue to Ljungskile and there carry out a new external check. At 16.17 the bus arrived at Ljungskile. The driver switched off the engine and alighted from the bus to carry out a fresh external check. He saw no smoke and continued towards Uddevalla, where he arrived at 16.42 hrs. He did another external check without seeing anything unusual and continued to Lysekil.

Shortly after 17.00 hrs he was approaching the Äskebacka bus stop where he was to set down passengers through the rear door. When he opened the rear door he clearly smelt an acrid smell. Suddenly the engine stopped and all the dashboard lamps came on, including the fire warning lamp. He re-started the engine which, however, stopped again after a second or so. In his rear view mirror he saw smoke pouring from the side cover outside the engine on the right-hand side. He decided to evacuate the bus. However, the door control at the driver's seat position was not working so he opened the forward door with the emergency opening control. When he had evacuated the passengers and discovered flames under the engine compartment he re-entered the bus to check that nobody was still in it. As he passed the engine compartment on his way back he heard a loud explosion from it. He hurried out, whereupon he saw that the fire had broken through the floor of the passenger compartment over the engine. A minute or so later the whole bus was in flames. The fire service arrived on the scene at about 17.40.

1.2 Injuries to persons

	Crew	*Passengers*	*Others*	*Total*
Fatal	–	–	–	–
Serious	–	–	–	–
Minor	–	–	–	–
None	1	25	-	26
Total	1	25	-	26

1.3 Damage to vehicle

Total write-off.

1.4 Other damage

The road surface under the bus was damaged by fire. Water from the fire-extinction and waste fuel ran down into a ditch at the side of the road.

1.5 The driver

At the time the driver was 59 years old and had held a valid licence with certification ABECEDE since 1973.

1.6 The vehicle

Owner/operator:	Lysekils Taxi Trafik Aktiebolag
Type:	Volvo Carrus B10M 70-B
Chassis number:	YV31MA715WA049096
Year of manufacture:	1998
Total distance covered:	Approx. 110 000 km.

Following a registration test, the bus was first registered on 2 June 1998. It was built on a Volvo chassis type B10M. It was 14.85 m long and 2.55 m broad. Its kerb weight was 15 600 kg and its total weight 21 220 kg. Its turbocharged diesel engine was positioned behind the front axle, under the passenger compartment and baggage compartment.

The engine compartment, lined with soundproofing material, had the cooling aggregate to the left in the direction of travel while the turbocharger was to the right with the engine block between them. An inspection hatch into the engine compartment was let into the floor of the baggage compartment. Through this hatch it was possible to see the high-pressure fuel pipes and the cylinder heads. A metal sheet was mounted over the turbocharger. This was fixed to a frame member with a space of some millimetres between it and the frame.

The engine was supplied with fuel via the fuel pipes. The pressure in the pipes varied with output and torque. At maximum power output maximum pressure was 1 000-1 150 bar and at maximum torque 825 bar.

The auto-ignition temperature of diesel fuel cannot be stated exactly since diesel oil is a complex mixture of different hydrocarbons. For individual hydrocarbons a more exact temperature can be given. A typical value for standard diesel is the temperature interval 210-230 °C and for MK1[1] fuel 220-250°C. Particulars on thermal ignition point (auto-ignition temperature) may vary appreciably, largely because this is hard to determine. The heated surface with which the fuel comes into contact, for example, is of great significance. For a large surface and mass, a lower temperature is needed for auto-ignition than for e.g. a thin wire of small mass. An example of a large surface can be parts of a turbocharger or manifold.

The temperature of the turbocharger depended on power output. At maximum output the temperature may be calculated to about 600 °C.

1.7 Meteorological information

The weather conditions did not contribute to the occurrence of the incident.

1.8 Site of accident and vehicle wreck

1.8.1 Site of accident

At the site of the accident, national route 161 runs mainly in a north-easterly – south-westerly direction, through fairly hilly country.

[1] Engine fuel (diesel fuel) environmental class 1 (MK1).

1.8.2 The wrecked vehicle

When the Board examined the vehicle it was parked on workshop premises. It was almost entirely burned out, largely consisting only of the chassis and metal parts of the bodywork. To the rear, however, unburned portions remained, though these were affected by the heat.

When the vehicle wreck was examined it was found that three high pressure fuel pipes to the engine showed damage that could be described as abrasion damage. Similar abrasions were also found on four manifold bolts and on the lower edge of the frame member. On one of the fuel delivery pipes the wear had caused a small hole in the tube.

Subsequent investigation revealed among the fire debris a rectangular metal sheet about 0.75 mm thick, about 33 cm long and 7.5 cm wide. The sheet, which was affected by heat, had abrasions corresponding to the damage on the fuel delivery pipes.

1.9 Medical information

Nothing has emerged that could indicate that the driver's mental or physical condition was impaired before the drive.

1.10 The rescue services operation

The alarm to the Uddevalla fire and rescue service came at 17.20. According to the operation report, the fire fighting operation commenced at 17.38. According to information received by the fire and rescue service during the alarm, smoke was coming from the engine compartment of the bus. When the fire service arrived the whole bus was in flames. The fire was dampened down with water from two pipes and coverage with medium foam. After approximately 15 minutes the fire was under control but damping-down operations were hampered by all the recesses in the bus chassis and the fact that the tyres had caught fire. During the extinction the road was closed in both directions. At 19.00 hrs the extinction was complete and the fire and rescue service assisted in tidying up the bus lay-by and the roadway. During this stage the police directed the traffic from one direction at a time.

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 Examination of metal sheet

The metal sheet found among the fire debris was investigated by CSM Materialteknik AB (CSM). The investigation report notes that

- the sheet was of surface-treated steel
- the surface layer was of zinc
- the steel was high-tensile, low-alloy construction steel for pressing.

According to CSM it is impossible from the analysis of the steel to state a more exact correspondence with a standardised steel quality since many standard steels fall within the scope of what the analysis shows.

1.12.2 Examination of the soundproofing material

Examination at CSM

CSM also examined the resorption properties of the soundproofing material in the service hatch to the engine compartment. There are three different designs of service hatch, depending on which spaces the hatches separate. The different material was as follows:

- a black foam material with a casting skin as sound insulation measuring 300 x 300 x 25 mm.
- a sheet approx. 320 x 130 x 30 mm of textile waste sandwiched between woven fibre.
- a sheet of wood laminate lacquered on one side.

In the test three test pieces (50 x 50 mm) were removed from each material and submerged in fuel. The changes in weight were determined at 23°C after 1, 3 and 6 hours and after 1,3 and 7 days, or until constant weight was reached. The pieces were then removed from the fuel and kept at a room temperature of 23°C. Weight changes were determined after 1, 3 and 7 days.

The results of this test show that foam plastic and textile waste absorb combustible oil rapidly and copiously. For the wood laminate absorption is considerably slower. The fuel then disappears fairly slowly from the material.

The above test method was proposed by CSM Materialteknik since there is no established method.

Manufacturers 'own examination

The manufacturers considered that the method used had not attempted to simulate the circumstances that could be imagined to prevail in an engine compartment where there was a fuel leakage. For this reason they asked to run a test of their own. The test, which was carried out under the Board's supervision, was conducted to show how an absorbent textile sucks up engine fuel in the form of a saturated mist in an enclosed space.

A test chamber measuring 140 x 93 x 66 cm was constructed in aluminium profile and transparent plastic boat cover material. The test chamber was then placed in a spraying chamber. In this way the temperature and air flow around the chamber could be kept constant during the test while at the same time ventilation was obtained.

The test chamber was considered to correspond to the engine compartment in question. At one end a high-pressure spray pistol was arranged so that only its nozzle was inside the chamber. The spray pistol was then connected to a high-pressure pump with a container for the environmental diesel fluid to be sprayed. Test pieces of the different types of engine compartment soundproofing material were then arranged in the test chamber in different ways.

1. Absorbent textile in the form of a whole panel was fixed along one side of the test chamber.
2. Test pieces cut to 50 x 50 mm with sealed sides and the test surface at right angles to the spray profile.
3. Test pieces cut to 50 x 50 mm with sealed sides and the test surface in the same plane as the spray profile.

When testing according to 1 above with a longitudinal spray a relative weight increase of 50% was obtained in two hours, which means that the absorbent textile had sucked up 500 g in a panel initially weighing 1 000 g. After two hours the absorption rate decreased so that only 7 g was added during the third hour. There were also clear differences depending on whether the spray was directed directly at the test surface or in the same plane as the surface. With perpendicular exposure (2 above) the weight increase was 400% in ten minutes. With the spray in the same plane (3 above) it took more than two hours to obtain the same result.

1.12.3 Fire resistance testing of bus seats

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. All the test results 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. There are still large differences in the views of different countries, even within the EU.

Since the fire in the bus developed very rapidly and led to almost total destruction, the Board considered it would be valuable to obtain a measure of the degree to which the fittings in the bus had properties that themselves caused the rapid burning. Against this background a fire resistance method was chosen that had been produced during the work on European standardisation for the testing of upholstered furniture.

The test object was placed on a scale platform and ignited in the seat and back cushion using a gas burner with a 30kW output. The ignition sequence lasted two minutes, whereafter the burner was removed. 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 1 339 kW. Total heat energy released during the test was 265 MJ. The average effective heat of combustion was 22.5 MJ/kg. Maximum heat radiation was 18 kW/m^2.

The measured heat effect from the fire gives information on the chances people have of evacuating and 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. 10m^2 floor area) with a door open. In the present test this effect was reached in just over 4 minutes and the maximum effect after 5 minutes. This means that one double seat of this type would be enough to set on fire a bus of corresponding size 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.

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 1.5 minutes.

1.13 The company's organisation and management

The bus was owned and operated by Lysekils Taxi Trafik AB. This company was part-owner of Buss i Väst AB. Regarding scheduled traffic the latter company handled the negotiations with the relevant traffic principals and assisted its part-owner with e.g. purchase of buses by producing requirement specifications. The actual traffic operation, however, was handled by the part-owners themselves.

1.14 Miscellaneous

1.14.1 Equipment for indicating fire in engine compartment or baggage compartment

There was a fire alarm system in the bus with three heat detectors in the engine compartment: one by the starter motor, one by the fuel pump and one in front of the engine. There was no detector in the space on the outside of the frame member where the fire started. The sensors were simple heat detectors designed for placing in engine compartments. The type used in this bus has a sensor element the exterior of which is a flat sheet surface. The detector's connection leads and terminal space are protected from the atmosphere by a plastic shrink-on tube.

1.14.2 Fire-extinguishing facilities

The driver had access to a hand fire extinguisher.

1.14.3 Rules for fire-fighting equipment and fire protection devices

There are no established norms for the design of fixed fire-fighting equipment or detectors with wiring systems for buses. The only type of vehicle with such rules is forestry and constructional machines. These rules were produced jointly by the insurance companies and are published by the Swedish Insurance Federation under the heading "Rules for fixed fire-fighting equipment and other fire protection devices on forestry and constructional machines". The latest edition has reference number RUS 127:9 January 1998.

2 ANALYSIS

2.1 Origin of the fire

There is hardly any doubt that the fire started by diesel oil being forced out of the punctured high-pressure fuel delivery pipe and ignited by the heat generated by the turbocharger and engine. It is also evident that the delivery pipe was punctured through abrasion against the metal sheet later found among the fire debris. The situation was also worsened by the fact that, in all probability, before the ignition diesel oil had soaked into the soundproofing mats surrounding the engine and turbocharger. Regardless of whether the manufacturer's or CSM's measurement method is used, the mats clearly absorb considerable quantities of diesel oil in a fairly short time.

It has, however, been impossible to ascertain how the piece of metal sheet entered the engine compartment. There are several possibilities, of which none can be entirely ruled out. Yet it is quite clear that a contributory cause of the metal making its way into the engine compartment was the gap between the protective metal sheet over the turbocharger and the chassis member. The sheet forms a natural area on which to put objects down during work on the body, or inspection. A piece of metal placed on this surface may easily fall down into the engine compartment in the way that happened.

Increased environmental requirements have been placed upon heavy vehicles in recent years. Engine fuel must cause the lowest possible burden on the environment. However, to obtain as much energy from the fuel as previously, the pressure from the fuel pump has been increased. The high pressure causes finer spray particles, giving a higher degree of filling in the cylinders. At the same time this leads to more frequent fuel leakage. Vehicles must also create as little noise as possible. The noise requirements have entailed a raise in engine compartment temperatures since engines must now be surrounded with soundproofing material, etc.

2.2 Preventive measures

The current building-in of engines means that the possibilities of rapidly detecting a fire and reaching the engine compartment to extinguish it have decreased drastically.

In the view of the Board of Accident Investigation a logical development in this situation would have been to seek ways of prescribing the installation of suitable fire detectors and fire-fighting equipment. A type of detector formerly in frequent use had entirely open and unscreened detector elements in the form of fuses fixed between spiral springs. The mechanical protection for these detectors was simple plastic frames. This type of detector is clearly unsuitable. While the type in this bus was intended for mounting in engine compartments, it is clear that it reacted late since it gave no impulse to the fire alarm even though the bus was standing still and the fire near the engine was visible from outside. It has not been possible to determine the reason for this late reaction. However, in general terms it is established that, for the detector to function, the surrounding air must be able to flow undisturbed over the surface of the sensor. In addition, the detector must be fixed with its sensor so oriented that hot combustion gases may be expected to flow past it. The number of detectors and their placing should be selected to give a high probability that a fire in the engine compartment will affect the sensor very quickly.

In this bus – as in many modern buses – the engine is built-in so that the driver cannot gain rapid access to put out an engine compartment fire. Even if there are fire detectors as above, the driver in this situation can do nothing except evacuate the bus. This suggests that – where the engine is built-in in this way – there should also be a built-in fire extinguisher which is activated automatically in a fire or manually by the driver following a signal that fire has broken out in the engine compartment.

This issue has apparently been discussed but without a solution. Only in the case of forestry and constructional machines have rules been promulgated, and this only because the insurance industry has placed demands in the form of insurance conditions. The Board of Accident Investigation considers it a matter of urgency that the National Road Administration – if the Administration cannot itself promulgate national regulations - should seek to bring about improvements in the international vehicle regulations in this respect.

2.3 Possibilities for evacuation, etc.

Engine fires are a not entirely uncommon occurrence in buses and other vehicles. To entirely prevent the occurrence of fires is probably hardly possible since, naturally, inflammable liquids are present in close proximity to the engines. In the Board's view, efforts must therefore be directed to minimising the risks of personal injury in connection with engine fires. In the first instance this should be effected – as said above – through the installation of equipment which rapidly and reliably indicates and possibly also extinguishes a fire in the engine compartment.

However it must also be noted that the driver, when he started to suspect a fire and intended to evacuate the passengers, discovered that he could not open the door with the emergency control from the driving seat. Everything goes to show that the wiring that should have permitted the doors to be opened from the driving seat had been damaged in the fire. This strongly suggests that these wires should be located in such a way that they are not destroyed by an engine compartment fire.

It is stated in section 1.12.3 above that the rules for fire resistance testing of bus fittings are incomplete. Naturally it can also be pointed out that passengers 'clothing and the baggage they have with them in a passenger compartment may be of just as much significance for a fire taking hold as the bus fittings themselves. Nevertheless it appears highly desirable that methods be developed for fire-resistance testing of bus fittings.

3 CONCLUSIONS

3.1 Findings

a) The driver was qualified to drive the bus.
b) The bus complied with vehicle regulations in force.
c) Fuel leakage had occurred through abrasion of a delivery pipe.
d) Fuel spread as a mist throughout the engine compartment
e) Part of the fuel was sucked up by soundproofing material in the engine compartment.
f) The fuel was ignited in the engine compartment
g) The fittings in the passenger compartment were ignited by the fire.
h) The engine compartment was not directly accessible for fire extinction from outside.

3.2 Causes

The event was caused by a foreign body damaging the fuel delivery pipes in the engine of the bus.

Contributory to the consequences of the initial engine fire were the inadequacy of the equipment for fire detection and extinguishing.

4 RECOMMENDATIONS

It is recommended that the National Road Administration seek the production of equipment regulations for buses governing fire detection and extinction and devices for emergency evacuation *(RO 2000:01R1)*.