Incident report

D 1/2000 Y,
shortened version

Bus Fires in Finland during 2000

Translation from the shortened Finnish version

Onnettomuustutkintakeskus
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PREFACE

On 13.2.1999 there was a fire in a coach on the Kulju motorway near Tampere, considered by the accident investigation act as a major incident. The Accident Investigation Board of Finland set up an official investigation to explain the reasons for the fire. After that the Accident Investigation Board began to pay attention to bus fires that frequently recurred. A concern for passenger safety was foremost because buses transport more than 60% of all passengers who use public transport in Finland. During 1999 about 246 million passengers travelled in buses.

In the autumn of 2000 the Accident Investigation Board started the Bus Fire Project led by accident investigator Esko Lähteenmäki with Esko Värttiö, chief accident investigator, and accident investigator Reijo Mynttinen, all from Accident Investigation Board, as members of the team. Statistics of, and reasons for fires in buses were determined as project objectives. In the investigation report a summary of the fires, the causes of them, and passenger safety issues had to be presented, and safety recommendations made.

Once the project had begun the regional emergency services were asked to inform the person on duty at the Accident Investigation Board of any bus fires immediately. In addition insurance inspectors were asked to inform investigators of fire incidents.

The project group prepared a 'Bus Fire Investigation' form, which was sent in connection with the incidents to the bus driver involved and bus company owners for completion. From the form information about the vehicle and the fire incident, needed for the statistics, was obtained.

During 2000 a total of 33 fires in buses came to the investigators' attention. It is reasonable to assume that there were even more cases involving minor damage during the research period but because investigations only actively began in the autumn some of the incidents earlier in the year will not have come to the investigators' attention.

During the project the investigators had participated in some training sessions in the topic of coach services and had become familiar with the activity of the bus company owners' repair workshop. These presented opportunities for informing about the purpose and operation of the project. At the same time the investigators obtained valuable information from technical experts in the field of coach services. The project has also been written about in the Bus Federation's newsletter.

This investigation report has been submitted for review to the Finnish Vehicle Administration Centre, the traffic safety unit and the environment unit of the Ministry of Transport and Communications, the rescue department in the Ministry of the Interior, and the Finnish Motor Insurers' Centre. In addition, a draft was sent for unofficial statement to bus company owners and to other interest groups (11 in total).

The Bus Fire Project will continue throughout 2001, so this means that the period of investigation will cover whole year.

The project group thanks the valued co-operation of the individuals, bus company owners and other interest groups who provided information on fire incidents throughout the year 2000.

In this shortened investigation report Section *1 incidents and investigations by incident* have been expressed in table format. Furthermore, the *summary* section and section containing *statements* have been omitted.

CONTENTS

1 INCIDENTS AND INVESTIGATIONS BY INCIDENT

In this part the fire incidents are presented in chronological order in table format. The project group was informed of 33 bus fires varying from a small fire to the total destruction of the vehicle. The criterion for a fire was an open flame and that an effort was actively made to extinguish it. Incidents only involving overheating and smoke have not been included. Statistics on the fires are reported later with respect to different variables. Safety recommendations are presented in section 5.

As the Bus Fire Project only started at the beginning of September the information received concerning fires which preceded it is partially inadequate.

Incident No	Date	Vehicle Chassis	Vehicle Body	Year of model	Traffic form	Fire Severity[1]	Fire Cause
1.1	20.3.	Volvo B10M	Carrus Wiima 8073[2]	1996	City	2	Not known
1.2	April	Volvo B10LA	Carrus	1998	City	1	Abrasion and short circuit of battery cable
1.3	9.5.	Volvo B10B	Säffle	1996	City	2	Rupture of the injection pipe and fuel leak caused by it
1.4	10.5.	Volvo B10B	Säffle	1993	City	1	Abrasion and short circuit of battery cable
1.5	30.5.	Volvo B10B	Säffle	1996	City	2	Rupture of the injection pipe and fuel leak caused by it
1.6	24.5.	Scania K113	Lahti Eagle 560	1997	Charter	2	Rupture of the injection pipe and fuel leak caused by it
1.7	27.6.	Volvo B12	Carrus DeltaStar602	1995	Long distance	3	Overheating of the air conditioning equipment of fan in roof duct
1.8	1.8.	Mercedes	Neopalan 208L Jetliner	1990	Charter	1	Breaking of the can in the return pipe and consequent fuel leak
1.9	10.8.	Volvo B10B	Säffle	1996	City	2	Rupture of the injection pipe and fuel leak caused by it
1.10	12.8.	Volvo B10B LE	Carrus[3]	1997	City	4	Breaking of the return pipe and consequent fuel leakage
1.11	19.8.	Mercedes 0405	Mercedes-Benz	1995	City	2	Fracture of the turbo lubricating pipe retaining lug => pipe over the start cable bolt => short circuit => hole in pipe
1.12	8.9.	Setra / Mercedes	Setra S208H	1983	Charter	2	Short circuit in generator cable
1.13	23.9.	Volvo B10L	Carrus 204NU-2220[2]	1997	City	3	Loosening of the return pipe from banjo connector causing a fuel leak
1.14	4.10.	Volvo B10B LE	Carrus	2000	City	1	Overheating of disk brakes
1.15	14.10.	DAF	Granade Utik	1989	Charter	4	Not known
1.16	24.10.	Volvo B10LA	Carrus 204U-221	1997	City	1	Overheating of disk brakes
1.17	25.10.	Scania K-113CLB	Lahti Falcon	1991	Long distance	1	Vandalism; exhaust pipe blocked

[1] 1 = Begining of a fire, extinguished by hand extinguisher.
2 = Limited fire.
3 = Uncontrolled fire, extended to passenger compartment.
4 = Vehicle completely burnt.

[2] Articulated bus

[3] Low entry bus with bogie

1.18	26.10.	Volvo B10B/725	Carrus Delta Delta Star 301	1993	Long distance	3	Injection pipe wearing away and fuel leak caused by it
1.19	27.10.	Volvo B10B LE	Carrus – Wiima	1994	City	1	Abrasion and short circuit of battery cable
1.20	31.10.	Scania K 113 CLB	Carrus Star 502	1997	Long distance	1	Abrasion and short circuit of battery cable
1.21	31.10.	Volvo B10L-CNG	Carrus	1998	City	1	Oil leak caused by broken turbo shaft
1.22	2.11.	Volvo B10B LE	Lahti[4]	1999	City	2	Rupture of the injection pipe and fuel leak caused by it
1.23	2.11.	Volvo B10B LE	Carrus	2000	City	1	Overheating of disk brakes
1.24	23.11.	Volvo B10B LE	Carrus	2000	City	1	Overheating of disk brakes
1.25	29.11.	Volvo B10L	Carrus 204NU-2220[2]	1997	City	1	Oil leak caused by the fracture of turbo lubricating pipe
1.26	6.12.	Volvo B10LA	Carrus CityN204 U221	1998	City	1	Overheating of disk brakes
1.27	7.12.	Volvo B10M	Carrus K-202	1988	City	1	Damage of the fluorescent lamp choke coil
1.28	14.12.	Volvo B9M	Carrus	1990	City	1	Overheating of drum brakes
1.29	26.12.	Volvo B10B	Carrus 204L	1998	City	1	Overheating of disk brakes
1.30	28.12.	Scania K113CLBAA	Carrus Ajokki	1995	Charter	1	Overheating of the heater motor
1.31	29.12.	Volvo B10B	Säffle SK	1994	City	2	The series resistor of the heater ignited the plastic cover of the fan
1.32	30.12.	Volvo B10B LE	Carrus 204L-221 City	1993	City	1	Abrasion and short circuit of battery cable
1.33	31.12.	Volvo B9M	Kutter D 340	1985	City	1	Short circuit caused by abrasion of the generator cable

4 Low entry bus

2 ANALYSIS

2.1 Vehicles

2.1.1 Distribution by model and type

In 1999 there were about 9 450 buses in Finland of which approximately 4 300 were Volvo, 2 900 Scania and about 1 000 Mercedes.

In the bus fire incidents investigated there were four different types of engine and/or chassis manufacturers and several different types of bodies, from seven different manufacturers.

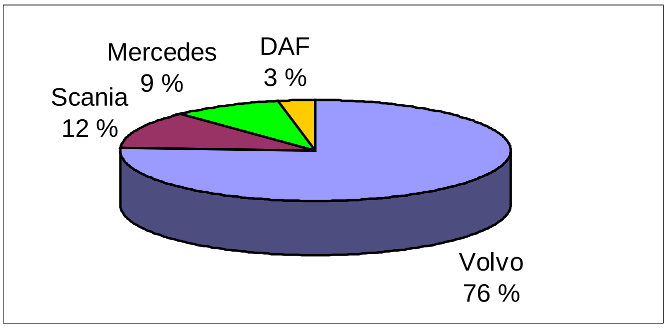

Diagram 1. Distribution of bus fire incidents investigated, by model.

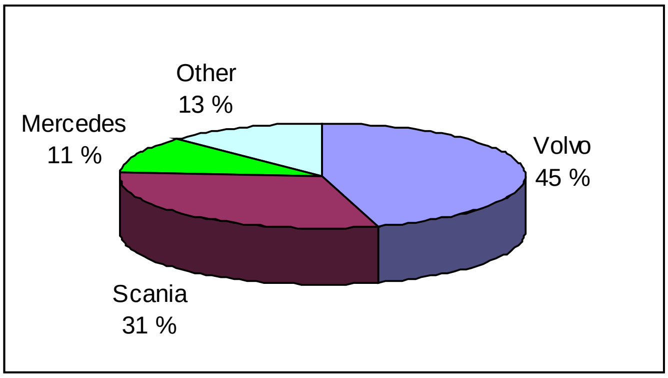

Diagram 2. Distribution of registered buses in 1999, by model.

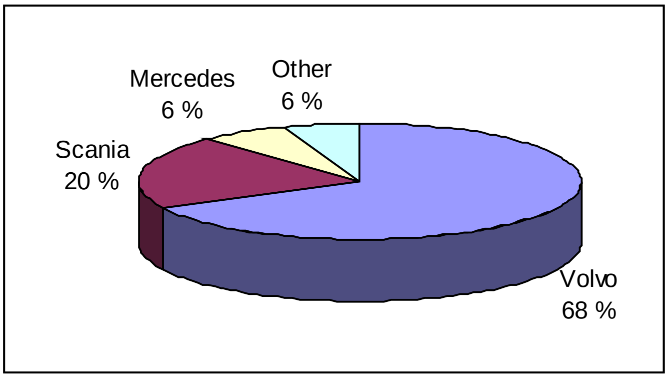

Diagram 3. Distribution of buses (low entry) in city traffic in 2000, by model.

Seven different manufacturers' bodies appear in the statistics, most of which have been manufactured in the Carrus factory in Finland (Wiima). Carrus has specialised in manufacturing buses for use in city traffic.

The main reason for the large share of the Volvo model in incidents investigated is the fact that Volvo represents 45% of all buses registered in Finland (according to the 1999 statistics) and 68% of the (low entry) buses used in city traffic (statistics for 2000). Furthermore, of all Volvo buses in city traffic (B10B and B10LA, total 19) there were three recurring causes of fire (a fuel leak, abrasion of the battery cable and overheating of the disc brake) which increased the proportion for this vehicle model. Volvo's share is also possibly increased due to the fact that the importer has its own very comprehensive statistical system. In the statistics there are also small fires in which there is no information available elsewhere; for example from the insurance companies or rescue services. The importer has made statistics available for investigators' use.

The fuel of one vehicle was natural gas, others used diesel oil.

2.1.2 Age Distribution

In the fire statistics the average age of buses is 4.9 years and in 1999 the average age was 11.3 years for buses in Finland. The oldest vehicle that had caught fire was a 1983 model and the most recent a 2000 model. Most fires (6 incidents) took place in 1997 models.

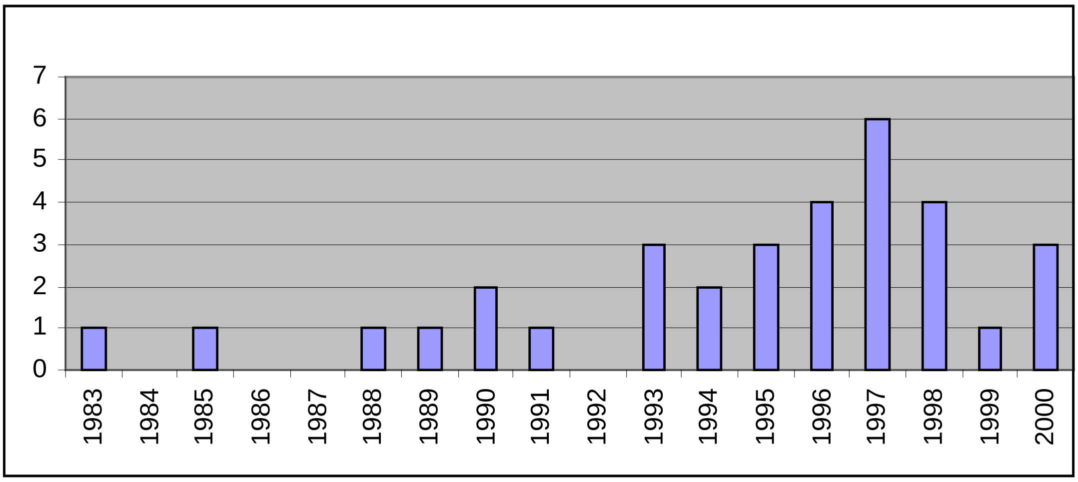

Diagram 4. Bus fire incidents investigated, by year of manufacture.

The statistics reveal that the average age of vehicles that have caught fire has been quite low. Vehicles had been driven an average of 430 000 kilometres, ranging from 12 600 to 927 000 kilometres.

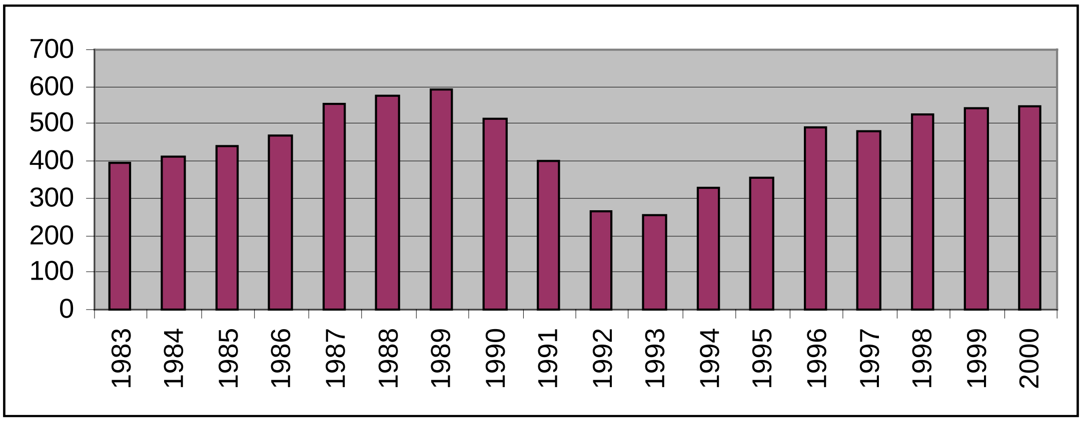

Diagram 5. Number of registered buses between the years 1983 - 2000.

2.1.3 Forms of traffic

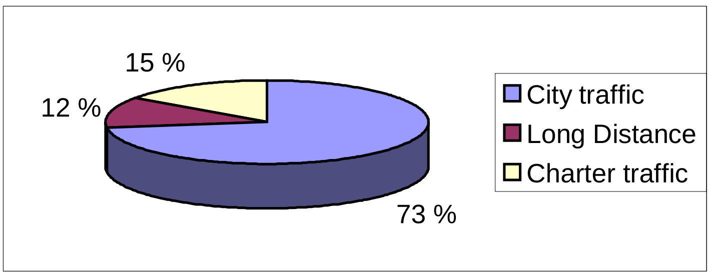

Diagram 6. Forms of traffic.

Clearly the majority of incidents happened in city traffic. This is influenced, among others, by the fact that low entry vehicle types are in use in city service, in which the same causes were repeatedly found (7 fractures of the fuel pipe, 6 disc brakes jamming and 3 cases of abrasion of the battery cable). Furthermore, one can conclude from the passenger numbers that there is more traffic in cities and that there are a large number of vehicles. A total of 71% of passengers travel in city traffic (the statistics of the Bus Federation (Linja-autoliitto) from 1997 to 1999).

2.2 Progress of the fire and passenger safety

2.2.1 Progress of the fire

Fires can be divided into two main types with regard to how they spread: the fire was restricted to the exterior of the passenger compartment, and fires, which spread into the passenger compartment from outside. Only two fires started inside the passenger compartment (cases 1.7 and 1.27).

A total of 31 fires started outside the passenger compartment, 21 of which started in the engine compartment, 7 in the brakes and 3 from under the body.

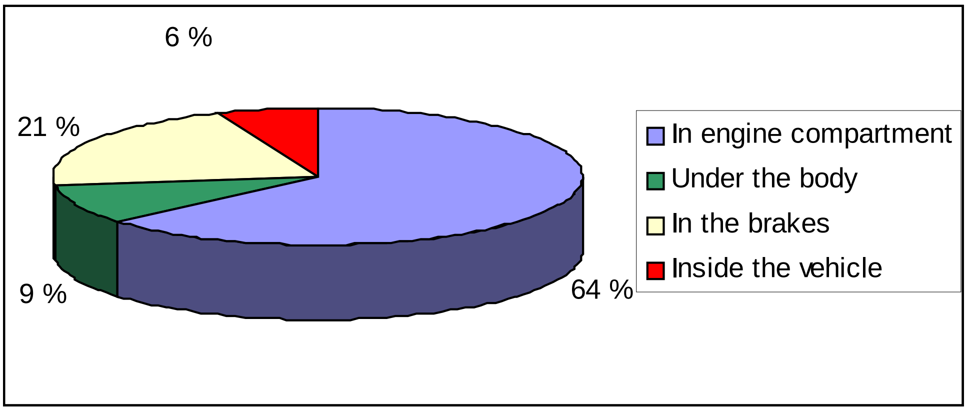

Diagram 7. Origins of the fire.

Five of the fires that started outside the passenger compartment spread to the passenger compartment. Two of the vehicles were destroyed beyond repair, two were badly damaged and one was slightly damaged. Furthermore, one of the vehicles in which the fire started in the passenger compartment was destroyed.

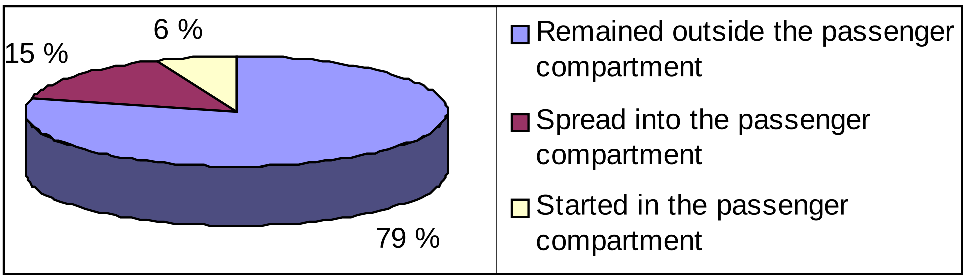

Diagram 8. Spreading of the fire.

2.2.2 Passengers' evacuation

Nine of the buses that caught fire were without passengers, in three vehicles there were less than 10 passengers, and in seven vehicles there were 30 or more passengers. In six incidents information about the passenger numbers was not obtained. There were on average 23 passengers in the buses.

There were no difficulties in passenger evacuation in any of the fire incidents. The doors opened as normal, or a backup system was used and all passengers left on their own initiative.

The fire incidents showed that the fire resistance of the engine compartment was so good that there was enough time for evacuation. On the other hand, the statistics reveal that safe evacuation time varies greatly depending on the cause of the fire. The evacuation time is essentially influenced by whether the fire started from a short circuit or fuel leak, and how long the engine still continues to run during the time when fuel is injected into the fire. There is an example of this in incident 1.18, in which driving continued for 50 to 100 metres after the fire was first noticed in order to find a suitable stopping place. During all that time the fuel sprayed into the burning engine compartment. The fire fighters arrived about six minutes after the vehicle had stopped but the fire already had moved to the rear of passenger compartment and had burnt the passenger compartment all the way to the eighth row.

In the short circuit situation the fire begins more slowly than in a fuel fire but the disturbances in the electrical system may cause new fires to start. In incident 1.12 the fuel fire which had started in the engine compartment also simultaneously caused an electrical cable fire in the front of the vehicle in the fuse and relay compartment that was in the recess of the front door. This illustrates that a fire that begins outside the passenger compartment can spread into the passenger compartment very quickly and, in the worst case, prevent egress.

Normally the fire moves into the passenger compartment from outside after the flames have broken either the rear window or the side window next to the engine. In the statistics there also is an incident in which the fire moved into the passenger compartment through the floor.

From the point of view of passenger safety it is important that the buses contain at least two doors. In vehicles used in city traffic there are usually at least three doors. The doors are wide and the vehicles are the easy to use low entry buses. In single-door vehicles the fire can make use of the door impossible in which case the evacuation has to be made through the emergency exits i.e. the windows and hatches. There were no single-door vehicles in the incidents investigated. According to the present structure regulations buses are required to have at least two doors (Ministry of Transport decision on the structure of buses and equipment 29.6.1990/637).

Passenger numbers varied from zero to 58, the average being 23. In several incidents passengers detected fire on the basis of the smell of smoke which had entered the passenger compartment. There was not a single case of difficulty in connection with evacuation. On the basis of this study one can state that in the fires which had taken place passengers' safety was not at risk. However, the situation could change significantly if, for example, there are disabled passengers in the vehicle.

2.3 Fire extinguishing methods and results

2.3.1 First-hand extinguishing methods and results

First-hand extinguishing is defined in this context as the actions taken to extinguish a fire before the units of the rescue service arrived at the scene. Of the 33 registered incidents it is known that the driver operated the fire-extinguisher in 23 of them. In three incidents more than one dry powder extinguisher was used. In four incidents the driver obtained help with first-hand extinguishing from other motorists. In one incident water was used to extinguish the fire. In four incidents an extinguisher was not used. There is no information available about fire extinguishing in five cases.

First-hand extinguishing succeeded in 17 incidents. The most common reason for failure was the premature discharge of the extinguisher's contents, i.e. the extinguisher's capacity was too small.

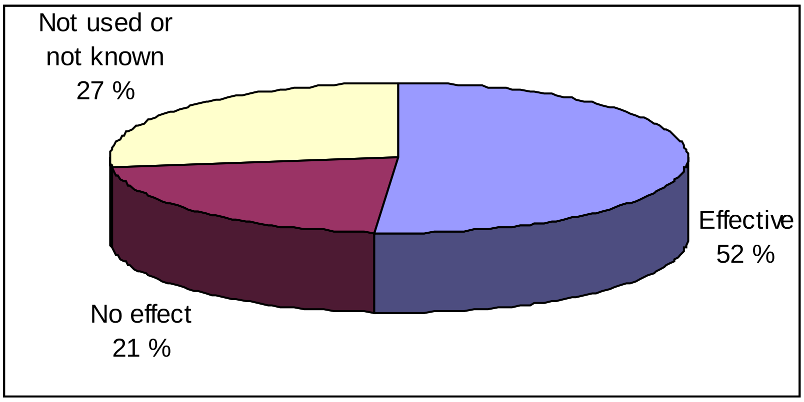

Diagram 9. First-hand extinguishing.

2.3.2 The significance of the first-hand extinguishing

The speed and effectiveness of first-hand extinguishing is of crucial significance to the extent of the damage. In vehicle fires the first-hand extinguishing will nearly always become the driver's task.

In an urban area the rescue service units arrive at the scene of the fire quite quickly, usually in less than 10 minutes. In contrast, in rural areas the time of arrival of the fire fighters is usually distinctly longer. The incidents show that if the driver has not extinguished the fire, or has not prevented it from spreading, and the fire fighters' arrival time is more than 10 minutes, then the fire will already have moved to the passenger compartment.

In 25 known incidents rescue services had to extinguish fires in 10 of them, in 5 of which the fire entered the passenger compartment, and in one of them the fire started in the passenger compartment. Three of the buses were destroyed. Of these the bus in incident 1.15 had burnt out before the fire fighters arrived.

In the statistics there are, among others, seven brake fires that were all extinguished by the drivers using a dry powder extinguisher. These incidents are a good example of the importance of the first-hand extinguishing because a brake fire that is not extinguished will spread to the tyres, the rubber components of the suspension and from them into the chassis and bodywork.

2.3.3 The capacity and skill in using the extinguisher

In buses a dry powder extinguisher with at least a 2 kg capacity is required; this has proved to be too small in many extinguishing situations, i.e. the extinguisher contents were exhausted before the fire was put out, or the fire re-ignited again when the extinguisher had discharged its contents. Only in four incidents was a 6 kg extinguisher available.

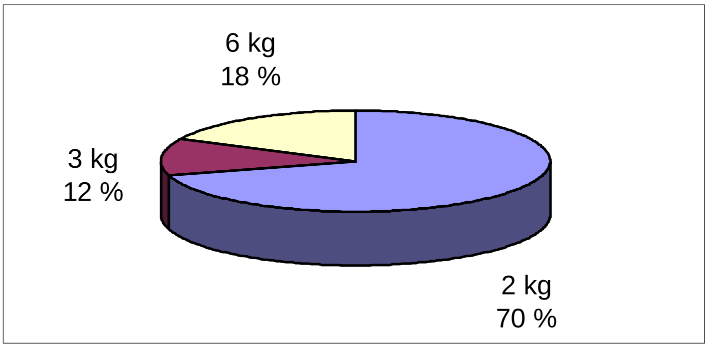

Diagram 10. The size of the fire extinguisher installed in vehicles, by incident.

In those incidents about which the size of the fire extinguisher is known there were 15 instances of a 2 or 3 kg dry powder extinguisher, and 4 instances of a 6 kg extinguisher. A 2 or 3 kg extinguisher was often found to be inadequate. It is thus justifiable to propose that every vehicle should be equipped with at least a 6 kg fire extinguisher.

The presence of even a large extinguisher will not put out a burning fire if it is not used, or not used properly. In the incidents investigated there were four fires in which the driver did not use an extinguisher; in two of them the drivers obviously did not know how to use them, and in one incident the extinguisher was not found because it was in the passenger compartment. In one incident the extinguishers of several vehicles were emptied to the engine compartment between the grating and the cover, where the extinguisher powder was directed at the air filter and not to the source of the fire; the vehicle was badly burnt.

The way the driver uses the extinguisher crucially determines the extent to which the fire damage is restricted. Bus company owners should therefore give every driver fire extinguisher training in which each trainee would be allowed to use the extinguisher. Personal extinguisher training increases the effectiveness of the extinguishing and lowers the threshold for the first-hand extinguishing. Drivers should also become acquainted with the structure of different vehicle types from the point of view of extinguishing fires. At the same time evacuation training should be given.

During the Bus Fire Project a few bus company owners have already exchanged the small fire extinguishers for 6 kg extinguishers and have begun training drivers in fire extinguishing.

2.3.4 Fire extinguisher hole

Because of the small capacity of the extinguisher its contents have to be directed immediately at the source of the fire. To direct the extinguisher contents at the fire source the engine compartment cover often has to be opened posing a safety risk to the person fighting the fire. When the cover is opened, the fire gets oxygen and may spread beyond the engine compartment. Furthermore, the effect of the fire extinguisher contents is at its best in a closed space. To direct the extinguisher contents at the source of the fire safely the engine compartment covers could be equipped with self closing extinguishing holes. The location of holes should be determined according to chassis and body so that the extinguisher contents can be directed freely at higher fire risk objects. Fire extinguisher holes like this have been successfully used in the engine guards of commercial aeroplanes of the piston engine era.

2.3.5 The fire fighters' part in the extinguishing of fires

In 21 out of 28 incidents where fire extinguishing information was available fire fighters were asked to attend. The average time of arrival was 11 minutes, the longest individual time being about 50 minutes (from Inari to Kaamanen in Lapland; about 60 km). In the Helsinki metropolitan area the time taken to arrive at the scene was on average six minutes. In rural areas the length of time to arrive ranged from 15 to 50 minutes. In ten incidents only the securing and cooling of the extinguished fire remained the task of the fire fighters.

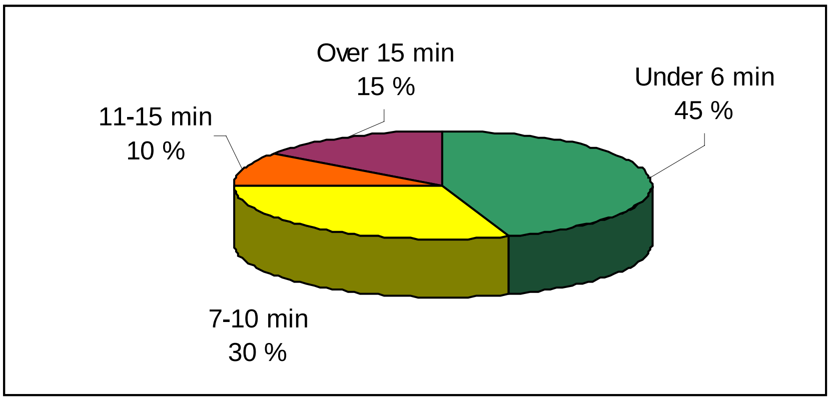

Diagram 11. Arrival time of the fire fighters.

2.4 Fire warning system

The investigation's statistical system did not give complete detail on how many vehicles contained an alarm system but it probably was the case in nearly all vehicles. The drivers reported that it operated in four cases. In the statistics there are 21 incidents in which the fire spread from the engine compartment and which should have triggered the fire warning system. However, it is possible that the warning lamp functioned more often than has been reported because in many fire incidents short circuits and device failures caused by the fire lit up several indicator lamps on the dashboard. Also information about the fire engages the driver's concentration so much that all observations are not recalled.

The bus chassis manufacturers provide fire warning systems for the engine compartment and require that the system is installed according to instructions. The system includes three temperature sensors, a wiring loom, supervision electronics and a warning lamp with audible signal in the dashboard. In the statistics the Volvo B10B chassis was the most common. The cylinders of the engine are in a horizontal position in this model, so the engine is low. Thus this chassis is the most common in the low entry buses of city traffic. These engines have been equipped with three fire sensors which are fixed to the wiring loom of the engine. One of the sensors is for higher temperature. However, this "hot end" sensor has been placed on the side of the engine where there are two other sensors. This accounts for the fact that, for example, a fire which has started as a consequence of the breaking of the injection pipe is not initially detected by the fire warning systems. To ensure a more perfect range the "hot end" sensor should be placed near the cylinder head in which there are, among others, an exhaust manifold, exhaust turbine, injection pipe and turbo lubricating pipe.

2.5 Fixed fire extinguisher systems

Fully automatic or semi-automatic fixed fire extinguishing systems have been developed for vehicles. Not a single burnt vehicle had these fire extinguishing systems. Of the fires 21 (63,5%) started in the engine compartment, so one can justifiably assume that the system would have put out all or the majority of these fires.

Fixed fire extinguishing systems in buses are extremely rare in Finland but they are used, among others, in forestry machinery.

In the discussions with the bus company owners and the body manufacturers it became clear that price was considered the main obstacle to the systems becoming more widespread. The fact is that the extra cost of the system installed in a new bus adds about 1% to the purchase price, so the obstacle to the decision to acquire is probably based on an ignorance of the real costs of the system. The passive attitude of insurance companies to the acquisition of the system has not been likely to promote its general use either.

3 CAUSES OF THE FIRES

The causes of the fires can be roughly divided into four categories: fuel leaks (28%), short circuits (24%), brake fires (21%) and other causes (27%).

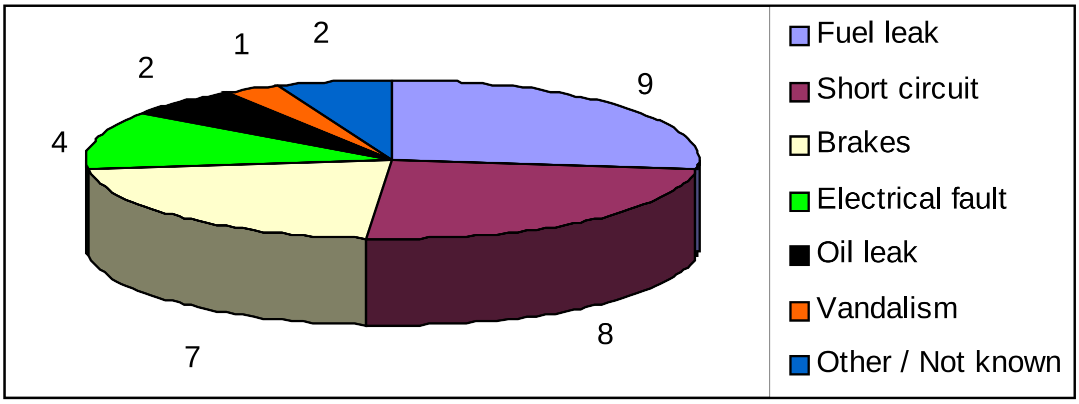

Diagram 12. Causes of the fires.

3.1 Fuel leaks

Fire in nine incidents was caused by fuel leaks. The injection pipe broke in five incidents (incidents 1.3, 1.5, 1.6, 1.9 and 1.22). Of these one line was into number 3 cylinder and four were into number 4 cylinder. Four of these pipes were near the hot running turbo and all were close to the exhaust manifold. Furthermore, one injection pipe began to leak as the consequence of the wearing out of the pipe (incident 1.18).

In addition to the breaking of the injection pipe, three fires were caused as the consequence of the fracture of the return pipe from the pump into the fuel tank (incidents 1.8, 1.10 and 1.13).

The reason for the fracture of pipes is almost invariably metal fatigue. The injection pipes have broken in vehicles that are new and have been little driven so fatigue fracture cannot be predicted in advance. In some incidents defective pipe supports can be shown as the cause of fractures. Furthermore, it is known that fatigue in the pipes is accelerated by the tension that remains in fitting the pipe, incorrect fastening torque and scratching of the surface of the pipes with, for example, work tools. Whether the large amount of heat radiation of the turbo has significance to the fractures is not known.

The pipes leading into and out of the fuel pump of the engine are susceptible to the shudder of the engine in use. Fatigue fractures have been found in these pipes, the Volvo B10B, B10L and B10M models in particular. Volvo already has realised this point and has published a maintenance and overhaul notice (22.11.2000) in which it is stated that the leaks are an extremely serious safety threat and that they must be corrected at once. Furthermore, the notice states that in production the rubber-sheathed plastic fuel pipes have been introduced. The notice recommends that if the old steel pipes have become damaged they should all be replaced with flexible pipes at the same time.

The heat of the turbo and the exhaust manifold forms a considerable fire risk, especially in the current engine assemblies in which the cooling of the compartment is worse than before because the cooler fan is not in the engine compartment. However, these fire statistics do not support the view that the new construction would have had the effect of igniting a fire in a single case either. If fuel or lubricant reaches the hot components of the engine, regardless of the engine construction, it will catch fire. The best solution for fire safety and also for noise reduction is to use turbos that have been equipped with water jackets and exhaust manifolds, such as those used in engines designed for use in boats. Water jacket components are significantly more expensive than those used in vehicles, but as the production numbers increase the price would probably fall.

3.2 Short circuit

A short circuit was the reason for fire in eight cases. Of these three fires were caused by abrasion of the starter motor cable against the hoist bracket of the engine (incidents 1.4, 1.19, 1.32). Inspection of a few vehicles of the same type (Volvo B10B) showed that the cable from the battery to the starter motor was far enough from the hoist bracket in some vehicles, but in a few the cable had been installed too near the bracket. In these vehicles the plastic guard pipe had already worn out the cable. If the cable is not moved further away or not protected from wearing out, the consequence is inevitably a short circuit and a fire. As stated in Volvo's previously mentioned maintenance and overhaul notice for the fuel system (published 22.11.2000) "*In connection with the inspection of the fuel system the condition of the existing cables in the engine compartment, their location and fastenings must also be checked so that abrasion has not occurred*." The instruction given probably refers to the year 2000 and the aforementioned short circuit incidents happened prior to that. From the point of view of vehicle users it is extremely important that the point should be specified in more detail.

Furthermore, in one incident the reason was a short circuit caused by abrasion of the battery cable between the cable and the fuel tank, and in two incidents wearing out of the generator cable insulator (the second is not certain).

3.3 Fires caused by brakes

In the statistics the third largest group is fires caused by the overheating of brakes. In six incidents fires started from overheating of disk brakes and one from overheating of the drum brake.

The cause of drum brake overheating is usually the wearing out of the brake linings so much that the S-cam turns too far and stays in the braking position.

The fires from the disc brakes in question have taken place in city traffic in which brakes are used a lot and the cooling periods remain short. As a consequence of heating the brake pads do not retract sufficiently, but they continue to drag and the heating continues. Overheating consequently ignites grease or oil from the wheel hub. If the fire is not quickly extinguished, it can spread into the tyres and structures of the chassis. In all incidents the driver managed to put out the fire with a fire extinguisher. Jamming of the disc brakes is an obvious type failure which chassis and brake manufacturers are searching for a solution.

In a few incidents the drivers reported steering drag before the fire but they continued driving until the brake overheated and caught fire. If there is steering drag, the driver has always to check the reason before continuing to drive. In addition to jamming of the brake, other serious reasons for steering drag are, among others, a puncture, damage to bearings and the malfunction of steering equipment, all of which require interruption to driving. These points should be brought up in driver training.

3.4 Other reasons

3.4.1 Electrical equipment failure

Electrical equipment failure was a cause of four fires. Two fires started from a heater fan, one fire began either in the air conditioning system in the roof of the vehicle, from its fan or in the roof fan duct, a standard feature in the vehicle, and one of the choke coil of the interior fluorescent lighting.

In connection with the investigation of the cause of fire it has been noted that in certain air fan types the electric motor speed series resistor has been installed in a fan casing made of plastic. When a fan ages and the bearings stiffen the fan’s motor requires more current, and because of this the temperature of the resistor increases. With the stiffening of bearings the rotational velocity of the fan reduces and cooling of the resistor decreases. As a consequence the resistor’s temperature rises and the plastic case of the fan catches fire.

The roof ducts and the heating pipe systems are often very dusty in older vehicles so, if the electric motor overheats or sparks, a fire can easily start and spread quite quickly. Special attention should be paid to the maintenance of electric motors, and to the cleaning of ducts and the maintenance of their filters. As vehicles age, attention should also be paid to the fact that the life of electric motors is limited and the motors should be renewed frequently enough.

3.4.2 Oil leaks

The investigation revealed that two fires were caused by an oil leak. In another, engine oil from a broken turbo shaft reached the exhaust pipe and the catalytic converter. In the exhaust pipe oil caught fire causing a flame outside at the end of the exhaust pipe. When the engine was stopped burning oil was able to leak into the engine compartment where it caused minor damage.

In the second incident the lubricating pipe of the exhaust turbo broke away from the base of the fastening flange on the side of the turbo. Oil sprayed from the fracture over the turbo and caught fire. The pipe had been installed in the vehicle as new about ten days earlier. Inspection of the fracture surface showed that a fatigue break had taken place, so the pipe probably remained under tension since it had been installed or its support had not been adequate.

3.4.3 Vandalism

Vandalism proved to be a cause of one fire (incident 1.17). The exhaust pipe of the vehicle had partly been obstructed with some object, possibly a stone, during an overnight stop. As a consequence hot exhaust gas flowed into the air filter along a connecting pipe that came from the cyclone. The exhaust gas lit the cyclone made of plastic from which the fire spread further into the air filter. The air filters and the air filter enclosure were damaged in the fire. At the same overnight stop exhaust pipes had also previously been blocked, and the incidents led to melting damage of the cyclone but not a fire. Drivers should be informed about this kind of recurring vandalism, so that they should check the external condition of the vehicle, including exhaust pipes.

3.4.4 Cause not known

In the investigation report there are two bus fires where the cause is not known.

One fire (incident 1.1) took place before the bus fire project. The driver noticed flames emerging from the engine compartment when the bus was at an overnight stop. The engine compartment was damaged in the fire.

In incident 1.15 the vehicle was completely burnt out. The driver of a car behind the bus had noticed smoke and had stopped the bus.

4 CONCLUSIONS

1. The passenger numbers in the incidents investigated varied from zero to 58, the average being 23. There were altogether 411 passengers in the vehicles. Passenger evacuation proceeded in all incidents without difficulty.

2. In the fires investigated passengers' safety was not at risk.

3. In 17 incidents the first-hand extinguishing by drivers prevented severe fire damage or complete destruction of the vehicle.

4. The main reason for the failure in the first-hand extinguishing was a fire extinguisher that was too small a size (2 - 3 kg).

5. The investigation stated that in some cases it was not known how to use the fire extinguisher in the most efficient way possible.

6. Of all fires 64% started in the engine compartment

7. Not one single bus contained an automatic fire extinguishing system in the engine compartment.

8. An automatic fire extinguishing system installed in a new vehicle costs 1% of the purchase price of the vehicle.

9. Fire alarms sensors had not been located correctly in all incidents. In several vehicles the fire alarm sensor in the engine compartment had not been installed close to the engine's cylinder head, from which several fires had started, for example, when the injection pipe broke.

10. Some causes of fire were repeated several times: jamming of disc brakes, breaking of fuel pipes (both the injection pipes and the return pipes) and wearing out of the cable from the battery to the hoist bracket of the engine.

11. In the incidents investigated the average age of buses was about 5 years, driven on average 430 000 kilometres.

12. The time taken for the fire fighters to arrive at the scene of the fire was about 6 minutes in the Helsinki area.

13. The spread of the fire from the engine compartment to the passenger compartment takes about 10 minutes, if the fire has not been extinguished or confined.

14. Of all fires 73% took place in city traffic.

5 RECOMMENDATIONS

5.1 Fixed extinguisher systems

All new buses should be equipped with an automatic or semi-automatic fixed fire extinguisher system. [D1/00Y/S1]

5.2 Extinguisher capacity

Investigators recommend that the Ministry of Transport and Communications should prescribe a fire extinguisher of at least 6 kg in buses instead of the current 2 kg hand extinguisher. [D1/00Y/S2]

The same recommendation is already in the investigation report C 1/1999 Y (Coach fire on the Kulju motorway 13.2.1999).

5.3 Fire extinguisher holes

Bus manufacturers should equip the engine compartment covers with holes for fire extinguisher nozzles, with a spring loaded lid that opens inwards. The location of the holes should be determined according to chassis and body so that the extinguisher contents may be freely directed to higher fire risk objects. The lid should be equipped with the picture of a hand extinguisher. [D1/00Y/S3]

5.4 Driver training

Bus company owners should give every driver training in the first-hand extinguishing and at regular intervals arrange practice in the use of fire extinguishers and passenger evacuation. [D1/00Y/S4]

The bus company owners should give the drivers training in the type of equipment to be used. Drivers should become conversant with the function, among others, of the vehicle's fire warning system and the indicators relating to it. The drivers should always read the vehicle manual carefully when the vehicle type is not familiar to the driver. [D1/00Y/S5]

In driver training the importance of observing the driving properties of the vehicle should be emphasised. If, for example, there is steering drag, the reason for it has to be determined before continuing to drive. There can be several serious reasons for steering drag, one of which is the jamming of the brake and its overheating. [D1/00Y/S6]

5.5 Importers' statistics and reporting responsibilities

Importers should compile statistics on fires in bus models that they represent. They should draw conclusions from them and should prepare a work update guide for prevention of similar fires. [D1/00Y/S7]

The importer holds a key position in reporting recurring model-specific faults which are related to safety. They have information about the owners and users of the vehicle models in question. Notices which are sent to the customers should be sufficiently clear, detailed and sufficiently 'commanding' in their tone.

5.6 Boosting maintenance and consideration of the fire safety guide

The vehicle user is also responsibility for the vehicle's fire safety.

The vehicle user should take care of:

- *maintaining cleanliness of the engine and engine compartment*
- *inspecting the condition of the fuel pipes and replacing them with new types of pipes if necessary*
- *undertaking fitting work, according to the instructions in the maintenance manual, by taking into account the correct torque in tightening and the support of pipes*
- *checking the fitting and condition of the battery and generator cables according to the scheduled maintenance service program. [D1/00Y/S8]*

The bus company owners should add to their own scheduled maintenance service program the fire safety guide "Bus and Trucks, Fire Safety Guide, 1999" drawn up by the Federation of Finnish Insurance Companies (Vakuutusyhtiöiden keskusliitto) and Insurance Group's Vehicle Repair Commission (Vakuutusyhtiöiden autokorjaustoimikunta) and implement its vehicle fire safety inspection form in Appendix 3. [D1/00Y/S9]

The same recommendation for adding the guide into the scheduled maintenance service program with is already in the investigation report C 1/1999 Y (Coach fire on the Kulju motorway 13.2.1999).

5.7 Improvement in the fire resistance of the soundproofing of the engine compartment

Soundproofing and heat insulation components in the engine compartment, or their surface materials, should be fire resistant. [D1/00Y/S10]

The same recommendation for adding the guide into the scheduled maintenance service program with is already in the investigation report C 1/1999 Y (Coach fire on the Kulju motorway 13.2.1999).

5.8 Location of the fire indicator sensors

One of the fire alarm sensors should be placed close to the cylinder head of the engine on the so-called 'hot side'. [D1/00Y/S11]

REFERENCES

The following references are filed in the Accident Investigation Board. Please note that the originals are published only in Finnish. Translation of publication titles here is merely for the convenience of the reader.

1. Decision of the Accident Investigation Board to start the project

2. Bus fire investigation form

3. List of bus fires during 2000

4. Compiled table of bus fires year 2000

5. VTT (Technical Research Centre of Finland) Research Report no. VAL24-001892 Report on the cause of a fuel pipe leak (incident 1.22).

6. Statement from the Criminal Investigation Department's criminal technical laboratory RTL 16045/1/00 6.9.2000: breaking of a fuel pipe (incident 1.10)

7. Statement from the Criminal Investigation Department's criminal technical laboratory RTL 16046/1/00 7.9.2000: breaking of an electric cable (incident 1.7)

8. BUS AND TRUCKS, FIRE SAFETY GUIDE**,** 1999 *Federation of Finnish Insurance Companies (Vakuutusyhtiöiden keskusliitto) and Insurance Group's Vehicle Repair Commission (Vakuutusyhtiöiden autokorjaustoimikunta (VAT))*

9. Statements from Investigation Report notes:
   Ministry of Transport and Communications' traffic safety unit and environment unit statement 16.5.2001
   Vehicle Administration Centre's statement 121/991/2001 23.5.2001
   Ministry of the Interior's rescue department's statement 2000-808/Tu-33 26.4.2001
   Insurers Group Vehicle Repair Commission statement 19.4.2001