Rail Accident Investigation Branch

Rail Accident Report

Train fire at South Gosforth
8 January 2013

Report 18/2013
September 2013

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Email: enquiries@raib.gov.uk
Telephone: 01332 253300
Fax: 01332 253301
Website: www.raib.gov.uk

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(Cover photo courtesy of DBTW)

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Summary

Shortly after 14:00 hrs on Tuesday 8 January 2013, a train travelling from South Shields to St James on the Tyne and Wear Metro system experienced an electrical fault soon after it left South Gosforth station. A fire developed under the rear car of the two-car train as it came to a stand, and smoke entered the passenger accommodation. There were 45 passengers in the rear car, and they used the emergency handles to release the doors, and evacuated themselves onto the side of the line, with assistance from the driver of the train. No-one was hurt, but there was damage to the electrical equipment and wiring of the rear car, and the overhead electrical supply line parted during the fire. The accident occurred on an above-ground section of line; if it had taken place in a tunnel, the amount of smoke that was produced during the fire might have resulted in serious consequences.

The fire was caused by a fault within the line breaker case of the rear car, and was sustained because the protection system associated with the electric power supply to the train did not operate until 45 seconds after the fault started.

The RAIB has made one recommendation addressed to the infrastructure manager and two addressed jointly to the infrastructure manager and train operator of the Tyne and Wear Metro, covering the fault in the line breaker, the radio system in use on the network, and the maintenance of the emergency door release handles on the Metro cars.

Introduction

Preface

1 The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability.

2 Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

3 The RAIB's investigation (including its scope, methods, conclusions and recommendations) is independent of all other investigations, including those carried out by the safety authority, police or railway industry.

Key definitions

4 The report contains abbreviations and technical terms (shown in *italics* the first time they appear in the report). These are explained in appendices A and B.

The accident

Summary of the accident

5 At around 14:08 hrs on Tuesday 8 January 2013, a two-car Tyne & Wear Metro train left South Gosforth station on its way from South Shields to St James. A few seconds after it left the station, an electrical fault caused severe *arcing* in under-floor equipment and a fire developed underneath the rear car.

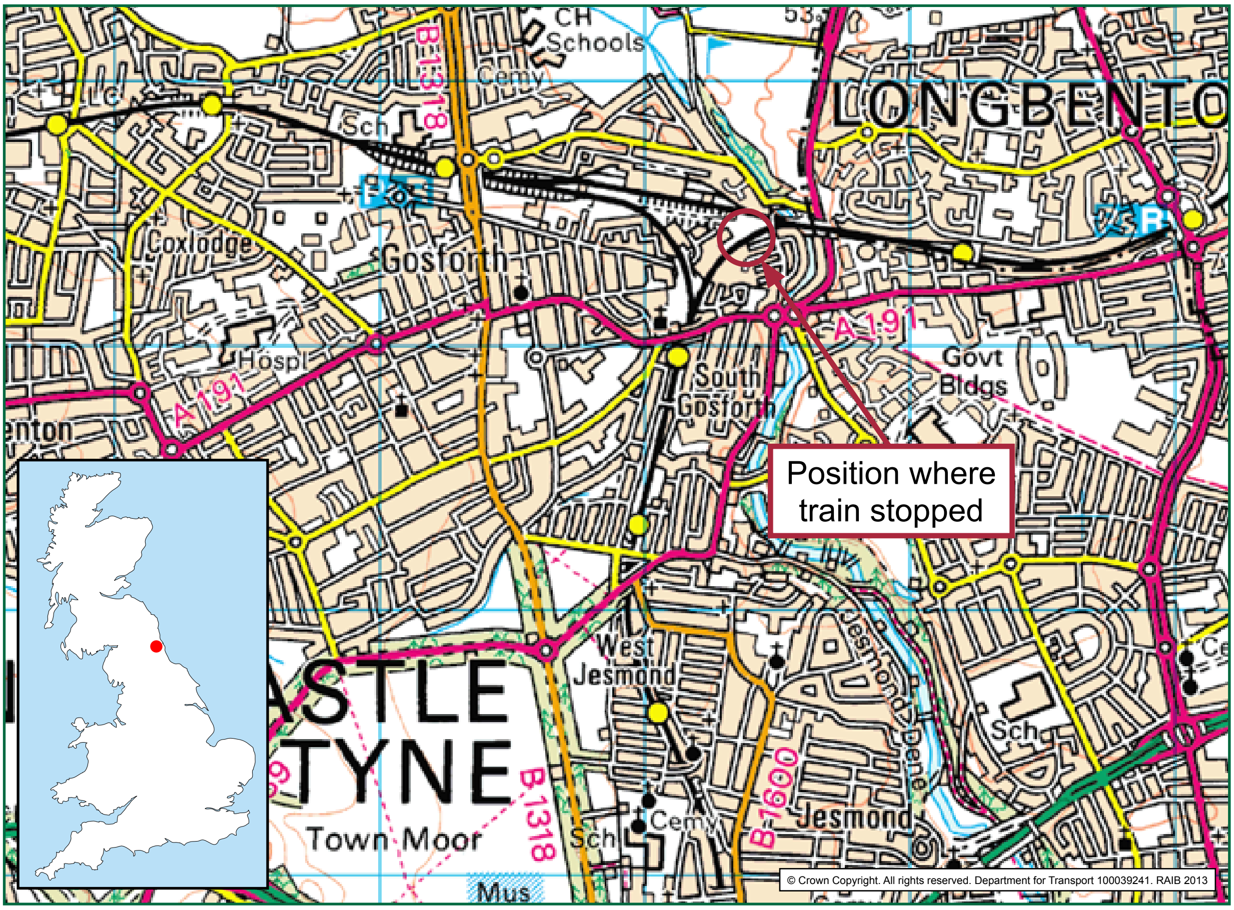

Figure 1: Extract from Ordnance Survey map showing location of accident

6 The train stopped, and a short time later the overhead contact wire parted and fell onto the roof of the rear car. The arcing which had caused the fire ceased after about 45 seconds, but not before a large amount of smoke had entered the rear car.

7 There were 45 passengers in this vehicle, and they used emergency release handles to open the doors and were then able to get out onto the side of the track, from where Metro staff escorted them to a place of safety nearby.

8 The emergency services attended and extinguished the smouldering equipment under the train. No-one was hurt in the accident. The train's electrical equipment and wiring was damaged, but there was no significant damage to the interior of the train.

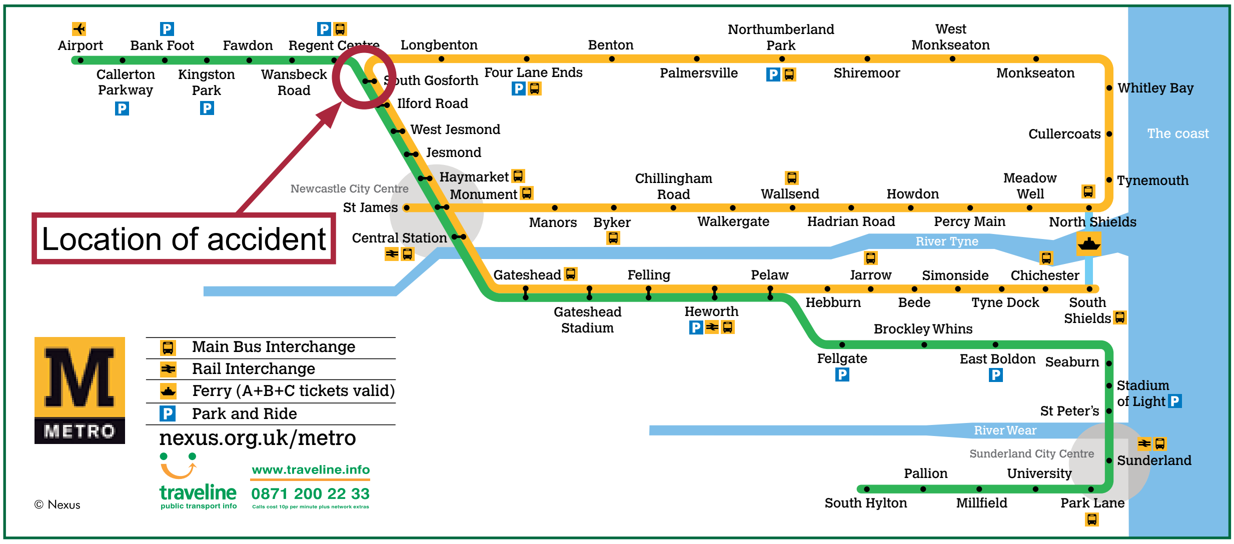

Figure 2: The Tyne & Wear Metro network (courtesy of Nexus)

Context

Location

9 The accident occurred on the Yellow line of the Tyne & Wear Metro, between South Gosforth and Longbenton stations (figure 2). The Tyne & Wear Metro opened in stages between 1980 and 1984, taking over the former British Rail North and South Tyneside routes, linked by newly-constructed lines under Newcastle city centre. It was subsequently extended to Newcastle Airport in 1991 and Sunderland in 2002. It uses articulated electric trains (cars) which are normally run coupled together in pairs, powered through overhead lines by a 1500 volt direct current (DC) supply.

10 At Gosforth South Junction the lines to Airport and the coast diverge. The train involved in the accident was outbound on the line towards the Coast. The system's principal depot is at South Gosforth, close to the site of the accident.

Organisations involved

11 The Tyne & Wear Metro system is owned by the Tyne & Wear Passenger Transport Executive, which trades as Nexus, and is the operating arm of the Tyne & Wear Integrated Transport Authority.

12 Since April 2010, the Metro has been operated under a concession by DB Regio Tyne & Wear Ltd (DBTW), a subsidiary of Deutsche Bahn AG. The concession includes operation and maintenance of the trains. DBTW employed the train drivers, system controller and power controller involved in the accident. Nexus remains responsible for maintenance of the infrastructure of the Nexus portion of the Metro (the section from Pelaw to South Hylton is owned and maintained by Network Rail), including the electrical power supply system.

13 Nexus and DBTW freely co-operated with the investigation.

Train involved

14 The train consisted of two cars, each being a two-section articulated unit running on three four-wheel bogies. The leading car was number 4086 and the trailing car, on which the fire occurred, was 4052. These cars were built between 1978 and 1981, following testing of prototypes which began in 1975.

15 The Metro fleet is currently being refurbished to improve the passenger environment and extend the life of the fleet to 2025. At the time of the accident, car 4052 had not been through the refurbishment process, which involves attention to the bodywork and interior but no significant changes to the electrical systems and controls.

Rail equipment and systems involved

Electrical protection - vehicles

16 Each Metro car has three *line breakers (circuit breakers)*, identified as LB1 to LB3, which are contained in a case below the floor of the car, adjacent to the centre bogie. The line breakers control the main 1500 volt supply to the traction circuit of the car. They should be opened by the driver when approaching *neutral sections*, and will also open automatically if the overload monitoring module detects a fault in the downstream traction equipment (figure 3). The line breakers are wired so that, when they are commanded to open, LB3 will open first, causing a *damping resistance* to be inserted into the circuit, and then LB1 and LB2 will open immediately afterwards, cutting power to all the 'downstream' equipment on the car. The line breaker assembly uses three means to break the flow of current and extinguish any tendency to arcing:

- the contacts separate;
- magnetic blow-out coils use a magnetic field to deflect the arc; and
- a blast of compressed air (from the exhaust of the cylinder that holds the contacts together) dissipates the arc.

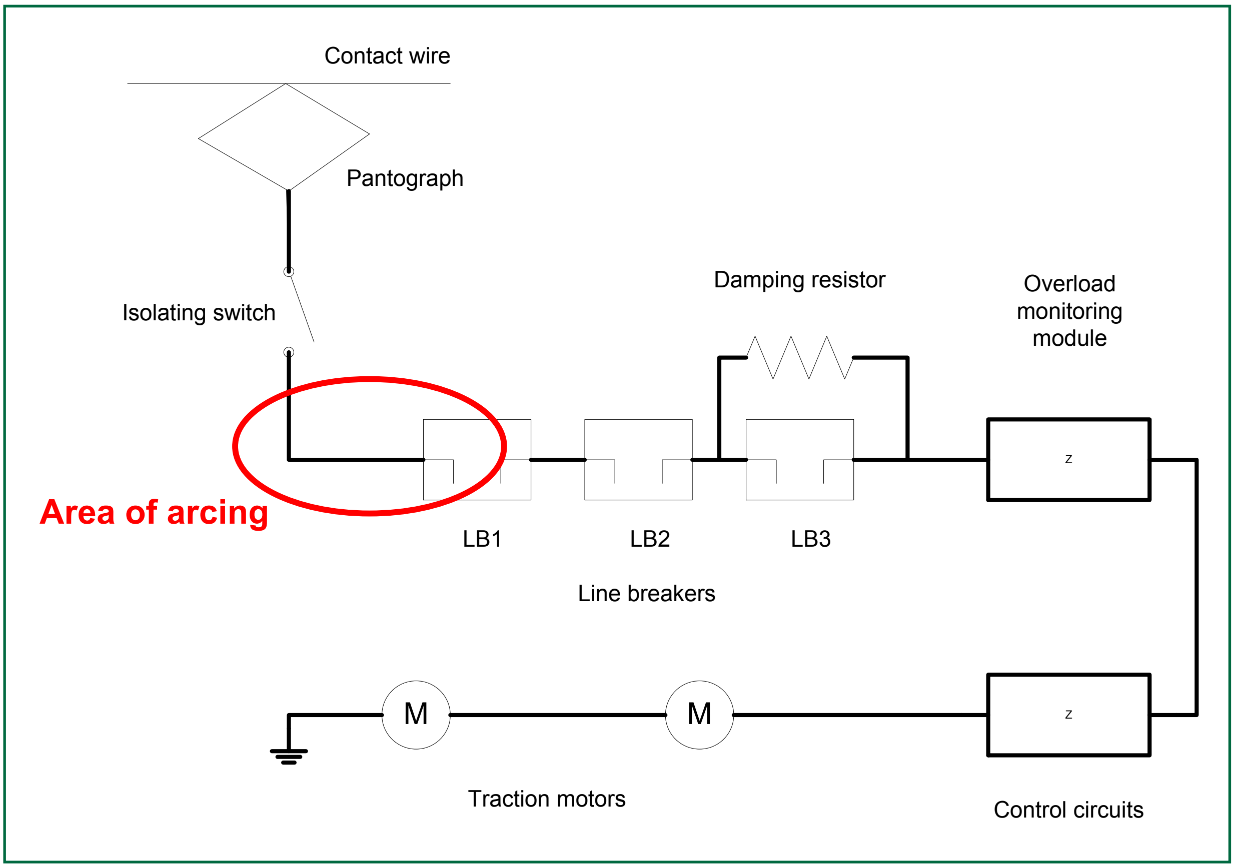

Figure 3: Metro car traction power circuit

17 The 1500 volt DC overhead line (OHL) equipment on the Metro exists in two different arrangements: a copper *catenary* supporting a solid copper contact wire, and, in some low-speed sections, including the accident location, *tramway-type* contact wire. The sections of OHL between Monument and Longbenton are *double-end fed* from sub-stations at Monument, Gosforth and Benton Square, with a section gap a short distance north of South Gosforth (figure 4).

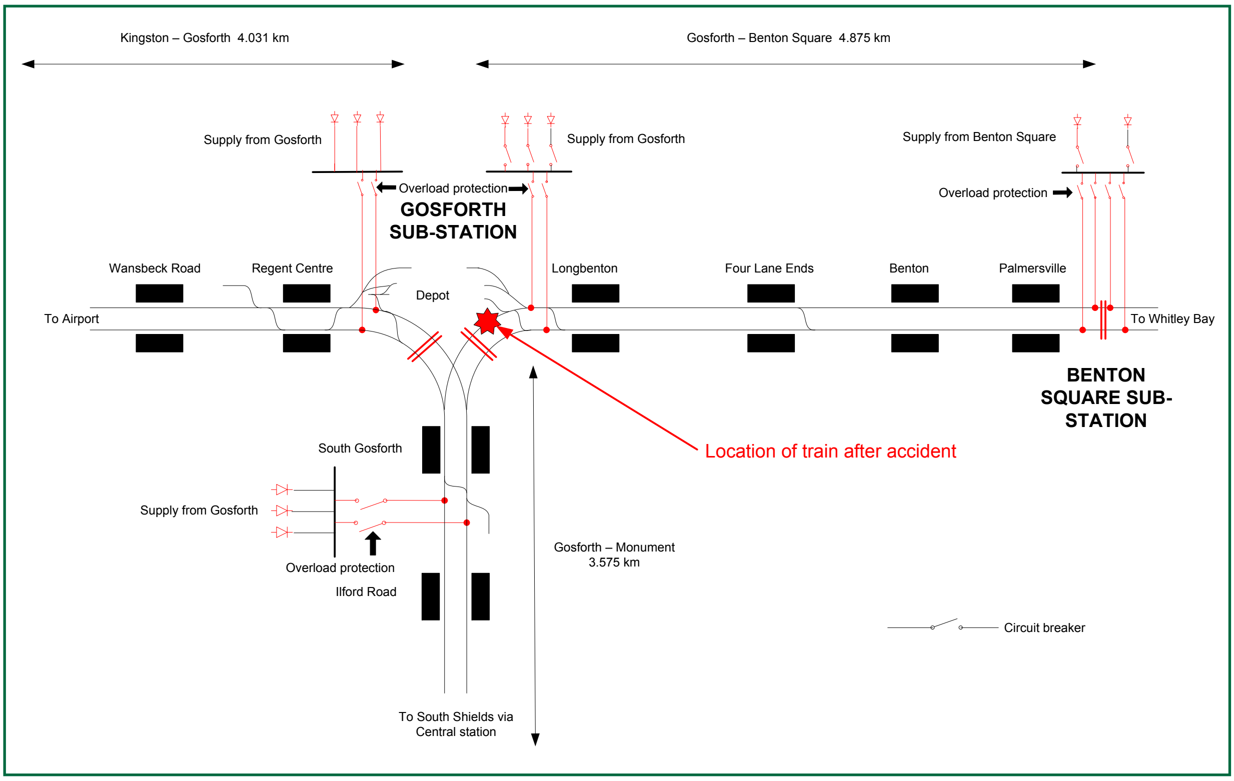

Figure 4: Electrical power supply arrangements in the Gosforth area

Electrical protection – power supply system

18 The power supply system requires protection from both large *overload* currents (typically associated with short circuits), and lower *over-currents* which, if sustained, may also indicate the presence of a fault. The current levels and timings that the various protection systems are set to operate at reflect the need for the systems to discriminate between the current drawn by the maximum number of trains likely to be in each section, and the currents that may indicate a fault condition.

19 The primary series overload protection for each sub-station consists of a bi-directional overload unit[1], set to operate the circuit breaker at the designated fault setting. This is set at between 1800 and 4000 amps as appropriate, depending on the likely load and the length of the section (which affects the amount of *line loss*). The section from Monument to Gosforth (3.6 km) is set to 3200 amps, and the section Gosforth to Benton Square (4.9 km) is set to 2400 amps (figure 4).

[1] Consisting of a direct acting attracted armature.

20 A safeguard against over-current is provided by time-delayed protection on each section, which permits high currents, but only for limited periods. This system has to allow for the starting current taken by Metro cars, which may be up to 500 amps for short periods. For this reason the over-current timing units are set to 800 amps on the main line sections. The timer for the Benton to Gosforth section is set to 50 seconds. The over-current protection will operate if a current rises above the set level, ie more than 800 amps but less than the amount required to operate the primary overload protection, and is sustained for the whole period over which the timer runs (the timer will re-set to zero each time the current drops below the set figure).

21 The electrical resistance of the overhead line equipment (the line loss) reduces the size of a possible fault current as the distance from the supplying sub-station increases. To provide protection from short circuits which occur a long distance from the sub-station, but for which the sub-station does not 'see' sufficient current to operate the primary protection system, mid-section protection is installed at the mid-point of some of the longer sections, including the Gosforth – Benton section. This consists of a *relay* set at 1500 amps, which will operate immediately if the current rises above this level, and send a signal to both ends of the section to open the sub-station breakers.

22 If a fault occurs close to one end of a section, although the primary protection at the adjacent sub-station may trip, the line losses may be sufficient to cause both the mid-section and the far end primary protection not to activate. In this scenario, the original Tyne and Wear Metro power supply design relied on the 800 A over-current timing unit to interrupt the fault current after 50 seconds.

23 However, since 1990, all double-end fed sections have been equipped with a sub-station *inter-tripping* system which sends a signal to open the circuit breakers at the opposite end of a section when a fault is detected by the primary overload protection. This is achieved through the use of telephone cable connections formed in pairs.

24 The inter-tripping equipment was installed in 1990, following two sub-station fires, both at Whitley Bay, in 1986 and 1988. Although the inter-tripping system often operates, and protects on-train equipment, during train faults, Nexus states that the inter-tripping was designed to protect the sub-stations rather than the equipment on the trains, and that train faults were not considered during the design of the inter-tripping system.

Staff involved

25 The driver of train 124 had just over one year's experience since qualifying as a driver on the Metro system.

26 The system controller on duty at South Gosforth had over twenty years' experience as a train driver on the Metro system before transferring to the control centre as a system controller at the beginning of 2011.

27 Both the driver and system controller were DBTW employees recently qualified in their current safety-critical roles, and were therefore (in accordance with DBTW's policy) subject to a two-year cycle of competence assessment.

External circumstances

28 There had been rain in the area during the morning, but at the time of the accident the weather was dry and overcast.

Events preceding the accident

29 On 8 January 2013 train 124, made up of cars 4086 and 4052, had been in service since 05:23 hrs. It arrived at South Gosforth at 14:06:48 hrs, and was held at a red signal while a train from the Airport direction passed across the junction. The signal cleared at 14:08:08 hrs, and train 124 moved off about 31 seconds later.

30 In this report, times in brackets indicate the elapsed time from when the train left South Gosforth. At 14:09:02 hrs, (23 seconds) CCTV evidence shows that there was a flash from the area of the line breaker case on car 4052, shortly before the train passed over Gosforth South Junction. It is likely that the driver had shut off power at this point, because there is a neutral section through the junction itself, and drivers are instructed to shut off power before passing through such sections, which opens the line breakers on the train (paragraph 16). At this point the train was in the Monument – Gosforth OHL section, and circuit breakers at both ends of this section opened automatically about this time, due to the operation of the overload protection systems (see paragraph 19), cutting off power to the train. CCTV shows that traction power to the train was lost (the interior lights went out), but the train continued to coast and ran into the next OHL section.

Events during the accident

31 The train coasted from the Monument – Gosforth OHL section into the Gosforth – Benton Square section (36 seconds). The circuit breakers at Gosforth substation immediately opened on overload (see paragraph 19). However, the section continued to be fed from the substation at Benton Square, 4.9 km away, for a further 45 seconds until the circuit breakers there opened on time delay overload (see paragraph 20).

32 During this period traction power to the motors of the train was not restored, because the line breakers had already opened, but an arc was sustained between the feed cable and earth in the vicinity of line breaker LB1 under car 4052, which resulted in a fire which almost completely destroyed the line breaker (see figures 7, 8 and 9) and generated a large quantity of smoke and flames outside the car (36 seconds to 1 minute 21 seconds).

33 Following the initial loss of power on the train, it coasted to a stop (1 minute 4 seconds). The driver did not apply the brakes, being unaware of the arcing and expecting that power might be restored at any time. About this time, smoke began to enter the passenger saloon via the articulation pivot at the centre of the car.

34 There were 45 passengers in car 4052. They succeeded in opening the doors on the left side (the side away from the other track) at the front and rear of the car (1 minute 18 seconds), but the handle of door 6 (at the rear of the leading section of the car) was too stiff for the passenger who tried it, and she moved to the rear section. No-one attempted to open the other door on that side of the car, probably because it was close to the source of smoke (figure 5).

35 The OHL contact wire melted and parted at the point where it was in contact with the *pantograph*, and fell onto the train roof and onto the ground on the right-hand side of the train (facing in the direction of travel) at about the same moment as the first door on the left-hand side of the train was opened by passengers (CCTV shows this happening at 1 minute 18 seconds).

Figure 5: Interior of car 4052 during the evacuation of passengers, 4 minutes 19 seconds after the start of the accident. Door 6 is on the right (image courtesy of DBTW).

Events following the accident

36 The train driver used the *cab secure radio* (CSR) in its normal mode to contact the network control centre (at South Gosforth) to advise that the train had lost power. The radio link was interrupted, and on making contact again the driver told the controller that the OHL had come down, and the controller (believing that the train might be in a radio 'black spot') acknowledged this and told the driver to use the company-issued mobile phone for further communication (see paragraph 94). However, the driver was unable to get through on the mobile phone because the network was busy (see paragraph 96).

37 While the driver was attempting to make contact, the passengers in car 4052 evacuated themselves onto the lineside through the two doors which they had been able to open, without apparently experiencing any difficulties (completed at 6 minutes 7 seconds).

38 The train driver, after using the public address system on the train to reassure passengers, then left the cab and made contact with the passengers from the rear car (8 minutes 47 seconds), took control of the situation at the scene, and escorted the passengers into an adjacent Nexus training centre car park (via an access gate (completed at about 11 minutes). There were no injuries.

39 The fire brigade attended, and after assessing the situation and confirming that electrical isolations were in place, used hoses to extinguish the smouldering equipment under the train about 40 minutes after it came to a stop (figure 6).

Figure 6: Car 4052 after the accident, with fire brigade in attendance. The doors nearest the camera in this view were opened after the arrival of the emergency services, and were not used for the evacuation of passengers (image courtesy of DBTW)

40 Trains on the opposite line were stopped at signals, which the system controller set to danger after being told by the driver of train 124 that the OHL had come down. The power controller initially switched off power on this line, but about 40 minutes later, the power was restored and one train which had been stopped at a signal close to where train 124 was standing was sent back to Longbenton, and its passengers were detrained there.

41 The OHL was repaired and re-energised at 17:09 hrs. The train was removed by a battery-electric locomotive, and services on the section of line from South Gosforth to Four Lane Ends were resumed at 17:57 hrs.

The investigation

Sources of evidence

42 The following sources of evidence were used:

- witness statements;
- Closed Circuit Television (CCTV) recordings taken from car 4052 and South Gosforth station;
- site photographs and measurements;
- investigations following the accident carried out jointly by Nexus and DBTW;
- an examination of the vehicle involved; and
- a review of previous RAIB investigations that had relevance to this accident.

Key facts and analysis

Identification of the immediate cause[2]

43 **The immediate cause of the fire was electrical arcing following a fault in the line breaker case on car 4052.**

44 The fire was the result of a sustained arc, which burnt away much of the equipment in the vicinity of the line breaker LB1. This produced a large volume of smoke, some of which entered the passenger saloon.

45 The size and position of the arc is clear from the condition of the equipment in the line breaker case after the accident (figure 7).

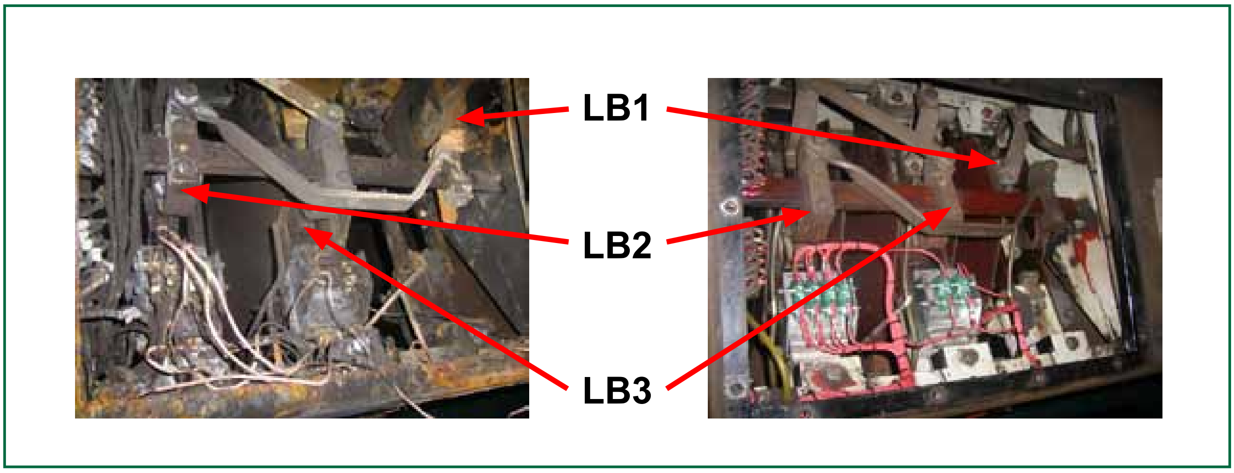

Figure 7: (left) Interior of line breaker case, showing damage to LB1; (right) the same equipment in an undamaged state

46 Line breaker LB1 was almost completely destroyed. Molten metal from the contactor assembly and support bar was sprayed around the interior of the line breaker case (figure 8).

Figure 8: Interior of the line breaker case cover (image courtesy of DBTW)

[2] The condition, event or behaviour that directly resulted in the occurrence.

Identification of causal factors[3]

47 The accident occurred due to a combination of the following causal factors:

- a fault developed in the area of line breaker LB1 of car 4052 (paragraph 48);
- there was no on-train protection against a fault current which develops between the pantograph and the overload monitoring module (see paragraph 57 and figure 6); and
- the power was not cut off between Benton and Gosforth as soon as the faulty train entered the section (paragraph 61).

Each of these factors is now considered in turn.

The line breaker fault

48 **A fault developed in line breaker LB1 of car 4052.**

49 The *flashover* which initiated the arcing was the result of an earth fault (ie a short circuit of the power supply on this design of system) on or around the input side of line breaker LB1. This is likely to have manifested itself, and caused the initial damage to the line breaker, when the driver shut off power to coast through the neutral section.

50 The upper section of LB1 (the vertical support bars, blow-out coil, top contact and brackets, braid and upper support block) was completely destroyed. The horizontal support bar was burnt through about two-thirds of its section (figure 9).

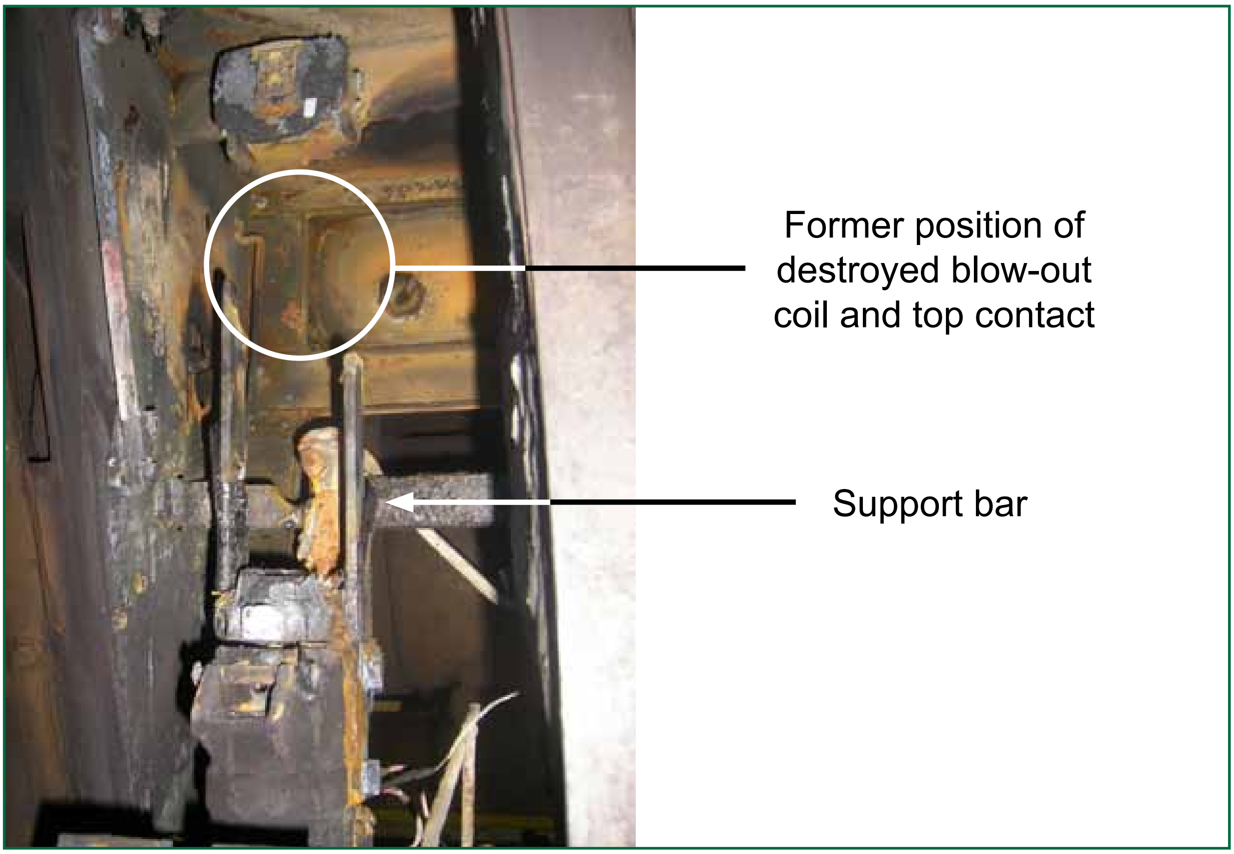

Figure 9: Damage to line breaker LB1 blow-out coil and support bar

[3] Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

51 After the accident, the other two contactor assemblies, LB2 and LB3, were found to be open and in good condition, suggesting that at the time of the accident they were not carrying excessive current.

52 The overload monitoring module detects the magnetic field generated by current passing through the supply cables downstream of the line breakers. If it detects an excessive current, it sends a signal to the line breakers, which open in the sequence described in paragraph 16. Its main function is to protect the vehicle's equipment in the event of a fault in the traction circuit, such as a traction motor flashover. In this case, the overload monitoring module had not operated (it is fitted with a 'flag', that can only be reset by a technician, which indicates if it has operated). It was removed from the vehicle after the accident by DBTW and tested, and found to operate correctly and within specification, at a current of 630 A.

53 The damage to LB1 and the surrounding equipment was so severe that it is not possible to identify the exact location or nature of the original fault, or the reason why it manifested itself when it did. Possibilities include degradation or damage to the insulation of the mounting bar, or a build-up of dirt.

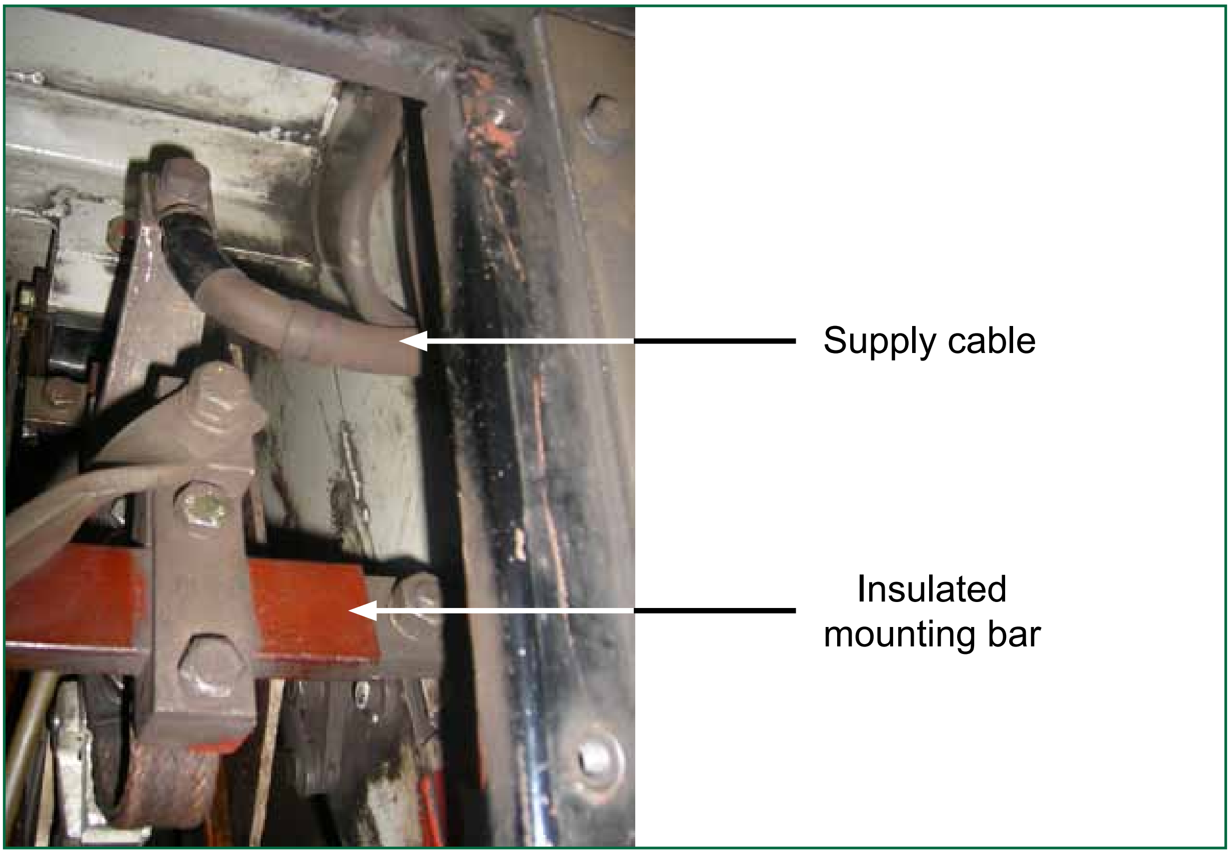

Figure 10: Line breaker mounting bar and supply cable in undamaged state

54 Examination of the remains of the line breaker equipment showed no evidence of any loose or defective connections which might have initiated the fault. In particular, the contact arm, braid connections and top connection block from LB1 were found in the case, although badly burnt and partly melted. All fasteners were present and tight.

55 Following previous incidents of line breaker failure (see paragraph 101) insulation condition is now being checked on all Metro cars at B exams (every 60,000 km, roughly every 3 - 4 months). No faults have been found so far, and there are no signs of degradation. There is no evidence of moisture ingress in line breaker cases.

56 The line breaker assembly is part of the original equipment of the Metro car fleet. It was designed in the 1970s and uses components and materials typical of that period. Some materials have been changed during the service life of the fleet (eg the *arc chutes*, and other insulating materials, no longer contain asbestos), but most of the assembly, including the insulation of the support bars, remains in its original state. The history of incidents involving the line breakers (see paragraph 101) shows that there have been at least six incidents over the last twenty years, four of which have been in the last five years. At present little is known about the mechanism of failure.

Vehicle electrical protection

57 **There was no protection against a fault current which develops between the pantograph and the overload monitoring module.**

58 The power supply to the train is taken from the overhead line by the pantograph, and passes through the main isolator switch and three line breakers before reaching the overload monitoring unit, which, by controlling the line breakers, protects the remainder of the traction power equipment.

59 The main isolator switch is manually operated from the outside of the vehicle. It is located in a separate case adjacent to the line breaker case. The switch on car 4052 was not damaged in the accident.

60 This arrangement of isolating switch and line breakers was a common feature of vehicles designed in the 1970s. Previous events involving fires in the line breaker cases on Tyne and Wear trains are described in paragraph 101.

Electrical supply protection

61 **The power was not cut off between Benton and Gosforth as soon as the faulty train entered the section.**

62 This arose due to a combination of the following:

- the fault current was not high enough to operate the 2400 amps primary protection system (overload current) at Benton Square sub-station or the 1500 amps mid-point line relay (paragraph 63); and
- the inter-tripping equipment between the sub-stations at Gosforth and Benton Square did not operate (paragraph 67).

Operation of overload trip at Benton Square sub-station

63 **The fault current was not high enough to operate the 2400 amps primary protection system (overload current) at Benton Square sub-station or the 1500 amps mid-point line relay.**

64 When the train (with a fault in the line breaker case) entered the Gosforth to Benton Square power supply section it was very close to Gosforth sub-station. As a result, the resistance between the train fault and the sub-station was low and the fault current supplied from Gosforth would have been high. Consequently the direct acting overload protection immediately turned off the supply from that sub-station.

65 The Benton Square sub-station (4.9 km away) continued to supply a lower level of current into the fault because of the higher electrical resistance associated with the longer distance between the train and the sub-station. In order for this to occur, the fault current must have been less than both the 2400 amps primary overload setting and the 1500 amps mid-point line relay setting, but there is no means of recording the value of this current.

66 The fault current was finally disconnected by the timed delay overload unit as designed after around 45 seconds (the timer had been set to a nominal 50 seconds) (paragraph 20), acting on a current which was more than its 800 amps setting.

Operation of inter-tripping system

67 The inter-tripping equipment between the sub-stations at Gosforth and Benton Square did not operate.

68 When a fault occurs on an overhead line section that is fed from both ends by different sub-stations, the sub-station inter-tripping system is designed to operate the second circuit breaker less than one second after the first one opens (paragraph 23).

69 In the accident on 8 January 2013, the inter-tripping system between the sub-stations at Monument and Gosforth operated as designed and discharged the current in response to the train fault which developed on car 4052 while it was in the Monument – Gosforth section. The train then coasted into the Gosforth – Benton Square section, with the line breaker on car 4052 already damaged, resulting in a powerful arc.

70 The inter-tripping system between the sub-stations at Gosforth and Benton Square did not operate when the circuit breakers at Gosforth opened on overload current of more than 2400 amps.

71 Subsequent investigation by Nexus found that this failure to operate was because an electronic component, an interface relay module, had failed at some point in the past. Nexus was not aware that this failure had occurred (see paragraph 76). At the time of the accident, work was in progress to renew the inter-tripping system, and this has since been completed (paragraphs 77 and 107).

Identification of underlying factors[4]

Electrical protection arrangements

72 Nexus and DBTW did not fully understand the risk associated with line breaker failures.

73 Despite the previous failures of line breakers (see paragraph 101) and consequent arcing incidents, Nexus and DBTW had neither analysed the reasons behind these failures, nor assessed the risk from such failures arising from the design of the electrical protection arrangements for the power supplies and the trains.

[4] Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.

74 Recommendations in previous internal investigations that the condition of the insulated support bars of the Metro car line breakers should be evaluated more closely resulted in tests on the bars in one-third of the fleet, which did not identify any faults in the insulation. The continued occurrence of such incidents, despite the negative test results, should have prompted consideration of the overall risk and the interaction of the systems that contributed to it. This should have taken into account the likelihood and potential consequences, particularly if a fire were to occur in an underground section of the system, and the possibility of a failure of the inter-tripping system.

75 **Nexus had inadequate arrangements for the inspection and maintenance of the inter-tripping system.**

76 Nexus did not have any process in place to monitor the health of the inter-tripping systems at each sub-station, or to maintain the systems. The state of the communication link (which transmits the trip request from one sub-station to the other) between the systems was monitored via an indication to the electrical controller at South Gosforth control centre. However, this was of little value to the controllers as they had no indication of the health of the overall system. There was no process in place for testing the inter-tripping system, unless a controller reported an indication of a fault with the communication link. No record was kept of any tests made when such reports were received. On 8 January 2013, the communication link for the Gosforth – Benton inter-tripping system was functioning normally, and the failure of the relay module was not visible to the control room staff.

77 Although no detailed records were kept, Nexus had begun to experience failures in the communication equipment of the inter-tripping systems. When the original manufacturer of this equipment went out of business, it became necessary for Nexus to repair failed components in-house, and the costs associated with this, as the failure rate rose, meant that by 2011 it had become more economical to replace the system. Trials with a new system began on the South Gosforth – Airport line in January 2012, and following the success of these, the new system was fitted to the rest of the network in stages between June 2012 and April 2013. The old system was still in use on the South Gosforth – Benton Square section when the accident occurred on 8 January 2013.

78 The new inter-tripping system is expected to be more reliable than the old. Nexus reports that no failures have occurred since the start of the trials in January 2012, and the equipment manufacturer claims a mean time between failures of at least 15 years for the various components of the system. The new systems are monitored via what Nexus describes as a ‘watchdog’ output. This output will send a fault indication to the network power controllers in the event of any of the following events occurring:

- a communication failure between the sub-stations;
- a hardware fault being detected at a sub-station;
- a software fault.

If the previous system had been equipped with similar monitoring, the fire on 8 January 2013 would probably not have occurred.

Factors affecting the severity of consequences

Parting of the OHL

79 There was potential risk to passengers from the fallen overhead line.

80 The overhead line parted about twelve seconds after the train stopped (as shown by the CCTV footage) and up to three seconds before the power was finally cut off from the South Gosforth – Benton Square section. At the place where the train stopped, the contact wire is a single conductor supported by solid droppers suspended from transverse cables (as distinct from catenary, figure 11), and is designed to withstand a continuous current of 360 A.

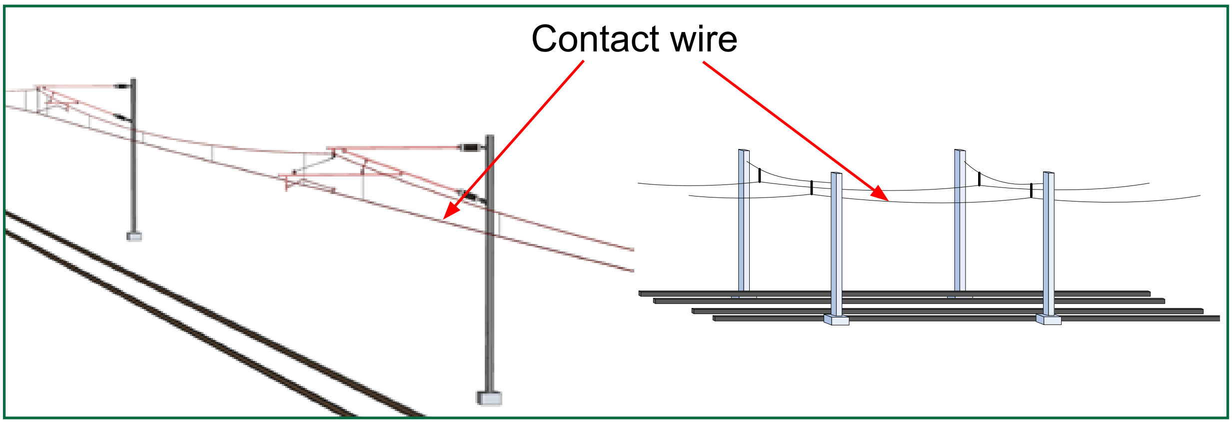

Figure 11: Catenary OHL (left) and tramway-type OHL (right)

81 The point where the contact wire failed corresponds to the position of the pantograph on the rear car, and it is likely that the high current flowing through a small contact area between the wire and the pantograph produced sufficient local heating to melt the wire. Examination of the wire showed marks of arcing on the wire on the side of the failure point from which the train had travelled.

82 Passengers were potentially at risk from the live contact wire in the period between the train stopping and the power being cut off. The forward section of the wire fell on the track on the right-hand side of the train, and the rear section came to rest on the train roof. The first of the train doors was opened, on the left-hand side, at the same moment as the wire parted. It is likely that the parting of the wire occurred about three seconds before the cutting off of the power. Although the risk to passengers in this accident was low, because the still-live end of the wire fell on the opposite side of the train from the open doors, in other circumstances the consequences could have been severe.

Smoke penetration into the passenger accommodation

83 A significant quantity of smoke entered the passenger accommodation of car 4052.

84 The CCTV from car 4052 shows that smoke began to enter the passenger saloon about one minute after the start of the accident, and it became thicker while the passengers were evacuating the vehicle (figure 5). However, subsequent examination showed no sign of any smoke deposits inside the car, and no-one needed treatment for smoke inhalation.

85 The smoke, generated from the burning metals and insulation material of the line breaker equipment, appears to have come through gaps between the sliding surfaces in the floor where the units are articulated either side of the central bogie. The small size of the gaps and the rapid evacuation of the cars prevented the smoke from causing any ill effects among the passengers.

Passenger emergency evacuation

86 **Some passengers had difficulty in using the emergency handles to release the doors.**

87 There are four sets of doors on either side of each Metro car. Two of the doors on the left-hand side of car 4052 (in the direction of travel) were opened by passengers and used to evacuate the car. Of the other two sets of doors, one was directly above the line breaker case which was the source of the fire, and was probably avoided by passengers because of the quantities of smoke rising outside it (figure 6 shows the smoke damage on the outside of the vehicle opposite these doors).

88 The remaining set of doors, not opened during the evacuation, were the second set from the front of car 4052 (identified as door 6). CCTV shows a passenger attempting to use the emergency door release handle to open door 6, but giving up after a short time and joining the evacuation from the other doors. After the evacuation, a number of passengers reported to the driver that they had had difficulty with the door release handles. Subsequent examination of the release handle mechanism for door 6 found that it was extremely stiff to operate, and tests using a diverse range of people showed that many passengers were likely to have been unable to obtain sufficient purchase to operate the handle far enough to open the doors.

89 The emergency release handle is shown in figure 12. It is designed to be pulled downwards to release the doors, and uses a wire-in-tube system to operate a latch on the door closing mechanism, and a valve to release the air pressure in the door actuator system. The angle at which the handle is mounted is intended to make it possible for it to be worked from outside the vehicle by a hooked pole wielded by the emergency services and passed through the open window immediately below, avoiding the need to break windows to enter the vehicle. However, this makes it more awkward for a person inside to use the handle without instruction and/or practice.

90 The regular examination schedule for the Metro cars (defined by Nexus, and carried out by DBTW) requires the operation of the emergency release handle for each door to be checked during each ‘A’ exam. These generally take place every 12000 km (approximately three weeks running). DBTW’s records showed that these checks had been carried out on car 4052, most recently on 13 October 2012. The car was in Gosforth depot from 2 November 2012 to 2 January 2013 for a ‘D’ exam, which included under-frame equipment renewal along with traction motor, gearbox and associated work, but not checks on the doors. The RAIB found that staff in the Gosforth depot, where these checks are carried out, were accustomed to carrying out the functional test of the emergency release handles, which consisted of operating the handle and confirming that doing so released the doors. However, during and after the accident on 8 January, people who were not familiar with them found the handles difficult to operate and stiff, particularly so in the case of the handle for door 6 on car 4052 (paragraph 34).

Figure 12: Emergency door release at door 6 in car 4052

91 After the accident, DBTW tested the force required to operate the door release handles on two cars, neither of which were involved in the accident on 8 January. DBTW reported that the results of these tests showed a range from 25 to 36 kg(f) (55 to 79 lb(f)). DBTW reported that the test equipment was unable to develop sufficient force and failed when it was used on door 6 of car 4052.

92 DBTW does not have a specification for the force required to operate the emergency door release handles on the Metro cars. The design of the wire-in-tube mechanism means that it is likely that they will become stiffer over time, unless they are regularly cleaned and lubricated, but the inspection method used by DBTW, based on functional testing (paragraph 90) meant that cleaning of the wire-in-tube (as distinct from the door latch itself) only took place when depot staff were unable to operate the handle to release the doors. No records were kept of such cleaning or minor adjustments to the mechanism.

Observations[5]

Communications

93 **The train driver experienced difficulty in communicating with the system control centre.**

94 When the train lost power and came to a stop, the driver used the CSR to contact the control centre. The driver was able to inform the control centre that power was lost and the OHL was down near the train, but conversation between the driver and the control centre was interrupted after a few seconds when radio contact was lost. The driver made contact again, and the system controller then gave instructions to terminate the radio call and use the (DBTW issued) mobile phone for further contact. It has not been possible to establish why radio contact was lost during the first call. Nexus has investigated the performance of the radio system, and concluded that it was working normally throughout the course of the accident.

95 The CSR system has an 'emergency' button which is intended to give priority over other calls that may be in progress. The driver did not perceive there to be an emergency at the time, and did not use this button. This was probably not related to the difficulty in maintaining radio contact, and is not considered to have affected the outcome of the accident.

96 The driver tried to use the mobile phone (which had an inherent delay, because it had to be switched on, and then took some time while it initialised), but was unable to get a connection to the control centre. This may have been because of the heavy use of the mobile phone network in the area by passengers calling the emergency services.

97 Being unable to make contact with the control centre, the driver telephoned the emergency services directly and gave them details of the event and its location. The emergency services contacted the Metro control centre to confirm their attendance and the location of the accident.

98 The driver eventually made contact with the control centre by mobile phone after escorting the passengers to the reception centre.

99 The system controller asked the driver to use the mobile phone because of past experience of 'black spots' on the Metro network where radio reception was poor, and a belief that this was what had caused the loss of contact during the first call. However, the location where the train stopped is not a known 'black spot', and the reasons for the loss of contact have not been established.

100 Nexus considers that the present CSR system, although it continues to be monitored and maintained, is approaching the end of its operational life. This in turn presents a risk that maintenance and repair will become increasingly difficult. The present CSR system performs poorly when multiple calls are made (as is likely to be the case during an emergency). It has no portable function (ie the equipment is built into the driving cabs), so the driver would have had to return to the cab to use it. At the time of the accident in January 2013 Nexus had already decided to replace the full CSR system and was in the process of finalising the design specification. Nexus is now (September 2013) seeking tenders for a new CSR system, which is due to be commissioned by May 2015.

[5] An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but does deserve scrutiny.

Previous occurrences of a similar character

101 DBTW and Nexus report that there have been at least five previous incidents involving line breakers on Metro cars in the last twenty years. There are believed to have been other incidents, the records of which have not been kept. All of those listed below were investigated at the time by the operator. These were:

- On 14 May 1994, between Wallsend and Walkergate, a train consisting of cars 4075 and 4041 experienced a double end trip of the OHL circuit breakers, which tripped again after they were reclosed by the control room. Line breaker LB1 on car 4075 was completely destroyed. The company's investigation concluded that:

  'The series overload was caused by one of the line breakers on Metro car 4075 burning out with this probably having been caused by the line breaker initially closing and for some reason, seals or faulty E.P. valve, reopening slightly. When the contacts reopened they would have drawn an arc which would be forced out to the arc horns by the blow out coil action. Because the train was taking power still the arc would have been sustained and ionised gas would build up further sustaining the arc until the line breaker burnt out and went to ground.'

- On 17 January 1999, a fire broke out in the line breaker case of car 4074 as it departed from Chillingham Road station, coupled to car 4027. Investigation found that there was an incorrect connection on line breaker LB2, which had caused LB1 to be overloaded, and when the driver shut off power on entering the station, LB1 was unable to extinguish the arc which then occurred.
- On 5 April 2008, shortly after midnight, a fault developed on car 4080 which was in service with 4085 between Percy Main and Byker sub-stations, and both sub-stations tripped. Initially the driver was unable to identify any fault indications on either car, and the train continued in service, but at Wallsend at 00:21 hrs the OHL tripped again, and smoke entered car 4080. Passengers were evacuated into the other car and the train continued in service to its destination. On examination, line breaker LB1 was found to be burnt out. The company's investigation was not able to reach a definite conclusion as to the cause of the fault. Three possibilities were identified: incorrect setting of the contact breaker gap; an incorrectly fitted arc chute; or breakdown of the insulation on the contactor support bar.
- On 3 December 2010 at about 06:05 hrs, a train leaving Monkseaton experienced a line breaker flashover on car 4067, which was followed by parting of the OHL almost immediately when the circuit breakers at Whitley Bay sub-station were reclosed by the system power controller, in accordance with standing instructions. On this occasion, the initiating fault was considered to be snow ingress into the line breaker case, as an unusually heavy fall of fine powdery snow had taken place overnight.

- On 8 December 2011 at 16:48 hrs, a train was entering service from Monkseaton siding, running into Monkseaton station, when an earth fault on line breaker LB1 on car 4017 caused a single-end trip of the OHL supply. The system power controller reclosed the circuit breakers at Whitley Bay sub-stations, and then both sub-stations supplying the section tripped. This fed a large amount of energy into the line breaker on the train, which was now defective, leading to a fire in the line breaker case. There were no passengers on board this train. The investigation concluded, again, that it was not possible to be certain about the nature of the initial fault, but that it was most likely to be a breakdown of the insulation on one of the contactor support bars.

102 Following these incidents Nexus and, since the start of its concession in 2010, DBTW, carried out *flash tests* on the insulation of line breaker contactor support bars throughout the fleet. No faults were identified.

Summary of conclusions

Immediate cause

103 The immediate cause of the accident was electrical arcing following a fault in the line breaker case on car 4052 (**paragraph 43**).

Causal factors

104 The causal factors were:

a. a fault developed in the area of line breaker LB1 of car 4052 (**paragraph 48**, **Recommendation 1**);

b. there was no protection against a fault current which develops between the pantograph and the overload monitoring module (**paragraph 57, Recommendation 1**);

c. the fault current was not high enough to operate the primary overload protection system at Benton Square sub-station or the mid-point line relay (**paragraph 63, Recommendation 1**); and

d. the inter-tripping equipment between the sub-stations at South Gosforth and Benton Square did not operate (**paragraph 67, see paragraph 107**).

Underlying factor

105 Underlying factors were:

a. Nexus and DBTW did not fully understand the risk associated with line breaker failures and had not assessed the risk from such failures arising from the design of the electrical protection arrangements for the power supplies and the trains (**paragraph 72, Recommendation 1**); and

b. Nexus had inadequate arrangements for the inspection and maintenance of the inter-tripping system (**paragraph 75, see paragraph 107**).

Additional observations

106 Although not linked to the cause of the accident on 8 January 2013, the RAIB observes that:

a. some passengers had difficulty in using the emergency handles to release the doors (**paragraph 86, Recommendation 2**); and

b. the train driver experienced difficulty in communicating with the system control centre (**paragraph 93, Recommendation 3**).

Actions reported as already taken or in progress relevant to this report

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation

107 Nexus has installed a new sub-station inter-tripping system and has put in place arrangements for its maintenance. It is also inspecting and testing the new inter-tripping equipment as part of the sub-station 6/12 monthly inspection regime (**paragraphs 104d and 105b**).

Recommendations

108 The following recommendations are made[6]:

1 *The objective of this recommendation is that Nexus, with support from DBTW, should identify and mitigate the risk associated with electrical breakdown in the train line breaker assemblies.*

Nexus, supported by DBTW, should carry out a detailed assessment of the risk associated with faults in the line breaker unit, which should include:

- identification of actual and potential failure mechanisms and an estimate of their likely frequency;
- consideration of the possible effects of line breaker faults, taking account of the configuration and reliability of the electrical protection systems currently provided on the Metro system; and
- consideration of possible consequences, taking account of the potential for fire in high risk environments, such as tunnels.

Appropriate actions to reduce the risk and potential consequences of failures should be defined and implemented following the review (paragraphs 104a, 104b and 104c).

2 *The objective of this recommendation is to facilitate passenger evacuation from trains using the emergency handles to release doors by identifying a maximum level of force required to operate them and then periodically checking that handles comply with the identified maximum.*

DBTW, supported by Nexus, should establish the maximum level of force required to enable a diverse range (such as 5th percentile female to 95th percentile male) of passengers to easily operate the emergency door release handles on the Metro car fleet, and implement the necessary inspection and maintenance processes to achieve it in practice, taking account of the need to balance the ease of operation in emergency with the risk of undesired door releases (paragraph 106a).

continued

[6] Those identified in the recommendations, have a general and ongoing obligation to comply with health and safety legislation and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation to enable it to carry out its duties under regulation 12(2) to:

(a) ensure that recommendations are duly considered and where appropriate acted upon; and

(b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 200 to 203) can be found on RAIB's website www.raib.gov.uk.

3 *The objective of this recommendation is to improve the reliability of the radio communication system used on the Metro network.*

Nexus should review the communication systems used on the Metro network, establish an appropriate level of reliability/availability for them, and implement, in a defined timescale, the introduction of suitable improvements (paragraph 106b).

Appendices

Appendix A - Glossary of abbreviations and acronyms

CCTV	Closed circuit television
CSR	Cab Secure Radio
DBTW	DB Regio Tyne & Wear Ltd
DC	Direct Current
OHL	Overhead line

Appendix B - Glossary of terms

All definitions marked with an asterisk, thus (*), have been taken from Ellis's British Railway Engineering Encyclopaedia © Iain Ellis. www.iainellis.com.

Arcing	The flow of electricity through the air from one conductor to another. Arcing can produce visible flashes and flames.
Arc chute	Shield made of fire-resistant material designed to contain the products of arcs generated in electrical switchgear, and prevent damage to other equipment.
Cab secure radio	A radio system provided to allow signaller or system controller and train driver to communicate safety critical information as securely as if they were speaking on a land line.*
Catenary	A description of the complete assembly of tensioned wires that make up the overhead line (OHL) electrification system, consisting of the catenary wire, droppers and contact wire.*
Circuit breaker	An automatically operated switch designed to protect an electrical circuit from damage caused by overload or short circuit.
Damping resistance	A resistance inserted into a circuit to reduce the rate of change of current during switching.
Double-end fed	A section of overhead line electrification which is supplied with power from both ends.
Flashover	An uncontrolled electrical discharge, typically between two bare electrical conductors.*
Flash test	A test to evaluate whether the electrical insulation of electrical equipment or components has sufficient dielectric strength for the working voltage. DBTW use a 3 kV test machine for flash tests on Metro car equipment.
Inter-tripping	A system designed to open the circuit breakers at a sub-station feeding a double-fed section, immediately the circuit breakers at the sub-station at the far end of the section are tripped by a fault condition, by sending a signal automatically between the two sub-stations.
Line breaker	The circuit breakers which protect the traction equipment of a rail vehicle. They can be operated automatically or by the train driver.
Line loss	The reduction in voltage (and consequently in power transmission capacity) over the length of a section of overhead DC line, caused by the resistance of the conductor.
Neutral section	A short non-conducting section introduced into the Overhead Line Equipment to separate two electrical Sections, so arranged that a passing pantograph does not connect them either.*

Over-current	A current which is higher than the continuous rating of an electrical circuit.
Overload	A current which is so high as to be potentially or actually damaging to an electrical circuit.
Pantograph	The device fitted to the roof of an electric train that contacts the contact wire of the overhead line equipment, allowing the traction unit to draw current.
Relay	An electromechanical device that utilises an electromagnet to make and break related sets of electrical contacts. Therefore, one electrical signal can be used to determine the connection or disconnection of many other circuits.*
Tramway-type (overhead line)	A system for supporting the contact wire of an overhead line system without the use of catenary wire or droppers. It is generally only suitable for low-speed use.

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Any enquiries about this publication should be sent to:

RAIB	Telephone: 01332 253300
The Wharf	Fax: 01332 253301
Stores Road	Email: enquiries@raib.gov.uk
Derby UK	Website: www.raib.gov.uk
DE21 4BA	