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Mr Andrew Hall
Deputy Chief Inspector of Rail Accidents
Cullen House
Berkshire Copse Rd
Aldershot
Hampshire GU11 2HP

Dear Andrew,

Explosion inside an underframe equipment case at Guildford, 7 July 2017

I write to report¹ on the consideration given and action taken in respect of the recommendations addressed to ORR in the above report, published on 20 March 2018.

The annex to this letter provides details of actions taken by end implementers in response to the recommendation and the status decided by ORR.

We will publish this response on the ORR website on 20 March 2019.

Yours sincerely,

Oliver Stewart

¹ In accordance with Regulation 12(2)(b) of the Railways (Accident Investigation and Reporting) Regulations 2005

Initial consideration by ORR

1. The recommendation was addressed to ORR when the report was published on 20 March 2018.
2. After reviewing the report and the recommendation, ORR passed it to all TOC, FOCs and metro operators in the UK, asking them to consider and where appropriate act upon it and advise ORR of their conclusions. The consideration given to each recommendation is included below.
3. ORR also brought the recommendation to the attention of UK Tram, RSSB (Rolling Stock Standards Committee) and RDG.
4. Since initially writing to end implementers, ORR has written to London Underground and Transport for Wales asking them to take the recommendation into consideration and act upon it if appropriate. We will report on this in a future update.

Recommendation 1

The intent of this recommendation is to minimise the risk of a future capacitor failure on UK rolling stock traction systems leading to an explosion and possible harm to the travelling public and staff.

UK train operating companies in co-operation with the suppliers of their rolling stock (Rolling Stock Leasing Companies or Contracting Entities) should:

- a) review the design of the electric traction systems in their current fleets and check that there are adequate safeguards in place to prevent an explosion capable of causing harm in the event of a failure of a capacitor(s); and
- b) address any shortcomings identified in (a).

ORR decision

Arriva Rail London

5. We are satisfied with ARL response regarding Class 315 and 317 fleets. We have asked ARL to advise us of the outcome of their discussions with Bombardier Transportation regarding the Class 172, 378 and 710 fleets and any actions identified as a result.
6. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Arriva Rail London has:
 - taken the recommendation into consideration; and
 - is taking action to implement it, but ORR has yet to be provided with a timebound plan for actions covering all fleets.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

7. In its response on 20 July 2018 Arriva Rail London stated:

As per the UK rail industry process for reporting of high-risk safety defects (defined in standard RIS- 8250 issue 1), South West Trains raised initial and subsequent interim National Incident Report (NIR 3296) on their failed capacitors and incidents of explosion that they had as a result. Following issue of these reports on the NIR-Online database system, ARL assessed the applicability of the defects for all the fleets we operate. Based on the information provided in these reports, including details of the failed capacitors and stated likely failure causes of capacitors manufacturing defects, we concluded at the time that the NIR was not directly applicable to the Class 315, 317, 172 and 378 fleets that we currently operate as none of them are fitted with this particular type of capacitor.

In terms of the recommendation and learning points identified in the RAIB report, please find below the progress of our investigations and actions to date, grouped by the classes of fleets that ARL operate and will operate in the near future.

Class 315

This EMU class of vehicles have a DC traction motor system (differing from AC traction) and therefore do not employ any large capacitors in their design and operation. Whilst some capacitors do exist in their design, there are none which are deemed to be of sufficient size to cause concern. No further action is considered required for this fleet.

Class 317

This EMU class of vehicles have a DC traction motor system (differing from AC traction) and therefore do not employ any large capacitors in their design and operation. Whilst some capacitors do exist in their design, there are none which are deemed to be of sufficient size to cause concern. No further action is considered required for this fleet.

Class 172

The class 172 fleet consists of Diesel Multiple Units and therefore they have a diesel traction system as opposed to AC electric traction. We are however working with the Class 172 design and maintenance provider Bombardier Transportation on reviewing the design of the vehicles and understanding whether there are other capacitors fitted that may present risk of uncontained explosion. Bombardier Transportation have also held a meeting with the RAIB investigation team to obtain more information.

Class 378

The EMU class 378 Electrostar fleet that we operate is an AC traction fleet that deploys larger capacitors in its design and operation. We are therefore currently working with the design and maintenance provider Bombardier Transportation on a

review of the design of the electrical traction systems, ensuring adequate safety measures are in place in the event of a capacitor failure. As mentioned above, Bombardier Transportation have also held a meeting with the RAIB investigation team to obtain more information.

Class 710

The EMU class 710 fleet, currently being built, is an AC traction fleet that deploys larger capacitors in its design and operation. We are therefore currently working with the design and maintenance provider Bombardier Transportation on a review of the design of the electrical traction systems, ensuring adequate safety measures are in place in the event of a capacitor failure.

Arriva Trains Cross Country Ltd

8. We have asked Arriva Trains Cross Country Ltd to confirm if any other capacitors within the propulsion case require additional safeguards and if so, how that would be addressed.

9. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Arriva Rail London has:

- taken the recommendation into consideration; and
- is taking action to implement it, but ORR has yet to be provided with a timebound plan.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

10. In its response on 18 June 2018 Arriva Trains CrossCountry Ltd stated:

In response to your letter dated 25 April 2018, outlined below are the incidents experienced by CrossCountry relating to capacitors, and the containment/countermeasures implemented to mitigate the risk.

There have been 3 National Incident Reports raised against the Class 221 fleet following incidents involving capacitor related explosions. These are as follows:

- *NIR 1635 was raised by Virgin CrossCountry following an incident on 11th August 2003 whereby a traction capacitor exploded causing damage to a number of traction case covers on vehicle 60756 (221106).*
- *NIR 2000 was raised by Virgin CrossCountry following an incident at Barton Hill depot on 29th May 2005, whereby a degrading filter capacitor resulted in an explosion that blew off one of the CVS cover plates and severely damaged the others on vehicle 60351 (221101). The CVS cubicle is mounted inside the vehicle at number 1 end.*

- *NIR 2624 was raised by Virgin West Coast following an incident at Polmadie depot on 17th June 2010. During investigation of a traction fault, it was discovered that the main traction case on vehicle 60363 (221113) had suffered an internal explosion causing damage internally and to exterior inspection panels.*

As a result of these incidents a number of containment actions and countermeasures were developed by the Train Service Provider (Bombardier) and implemented on the Class 220/221 Voyager fleet as follows:

1. Change-out of capacitors A check of all capacitors was conducted on the 220/221 fleet. This check highlighted that there were two revisions of capacitors fitted to the auxiliary converter (CVS) A and B. Tests at the supplier concluded that the revision A capacitor was not rated for the cross country duty and should be removed from the fleet. In total 32 revision A capacitors were found on the fleet and subsequently replaced.

2. Mod 819-81-2939A (Authorised by the Operator August 2003) - Capacitor housing bottom and end covers (Inverter lower & end cover and Agate end cover)

This change incorporated slots to weaken the covers. The purpose of this exercise was to ensure that in the event of an explosive release of energy caused by capacitor degradation, the covers would burst and remain attached to the case rather than becoming detached. A strip of self-adhesive tape was installed to the rear side of each slot and the slot then filled with Sikaflex. This also ensured that any resulting deformation of case covers remained within gauge.

3. Mod 819-81-3203 (Authorised by the Operator December 2004) - Traction Case Temperature Monitoring - Test

To further evaluate traction capacitor degradation, temperature stickers and ibuttons (computer chip enclosed in stainless steel can) dataloggers were used to monitor temperatures. These items were installed on the input filter capacitor and busbar to gain temperature information during periods of reduced traction. The test was used to evaluate whether DC Link capacitors overheated when the unit performed repeated acceleration/deceleration duty on half power (2 vehicles isolated).

4. Mod 819-81-3277 (Authorised by the Operator July 2005) - Auxiliary Converter Software Version 15 – Trial

Static and dynamic testing of CVS software version 15 was undertaken on one unit. Testing comprised one day static testing followed by one day dynamic testing (unit not in service). This trial software change was intended to reduce the risk of a further capacitor explosion, by improving detection of a three phase capacitor reducing in capacitance or going open circuit. This was achieved by comparing each phase

voltage against the other two voltages. If there was a difference of 20V between any two phases, an imbalance was logged and the CVS inhibited.

5. Mod 819-81-3298 (Authorised by the Operator March 2006) - Addition of Pressure Switch to Detect Increase of Pressure Within Capacitor.

Degradation of the filter capacitor resulted in the accumulation of inflammable gases within the propulsion case. Measures had already been taken to mitigate the risk of damage from an explosion. This change addressed the root cause by connecting a pressure switch to each filter capacitor (2 per vehicle) via a length of tubing. The switch was set to trip if an internal capacitor pressure of greater than 1.7 bar was detected. Once tripped, a relay contact was opened, that in turn opened the excitation contactor to the alternator. The traction inverter was locked out and an excitation contactor closing fault indicated on the train LON.

6. Mod 819-81-3344 (Authorised by the Operator November 2006) - CVS Software Upgrade to Version I.

Following the minor detonation of a capacitor on 29/5/05, and trial software mentioned above, amendments to the CVS software (Version I) were implemented to detect a capacitor losing capacitance or becoming open circuit. This version of the CVS software was designed to detect voltage imbalance in the 400V supply by comparing the ripple content of the 3 phases. On detection of excessive ripple imbalance, the CVS inverter is locked-out. Testing demonstrated that this version of software was able to detect complete loss of a capacitor phase immediately and to detect 50% capacitance loss within a few minutes. An existing TMS anomaly 3518 was used for reporting a fault of this nature.

7. Mod AVM06096 – CVS Ventilation (Authorised by the Operator May 2007)

Following the explosion on the VXC CVS on 29th May 2005, a temporary ventilation modification was implemented. This was to loosen the bolts on the CVS cubicle fan and middle covers to allow air to ventilate the case and dilute any gases that may be produced. Modification AVM 06096 represents a more permanent modification, which is based on the same principle as the temporary modification. Holes have been drilled and a filter added between the CVS cubicle fan area and the middle compartment. A ventilation grille has also been incorporated near the top left hand corner of the middle compartment cover. Air is forced into the middle compartment through the filter, past the three phase capacitor and out through the ventilation grille in the compartment cover.

Since the incident on 17th June 2010, CrossCountry has not experienced any further problems relating to capacitors on its train fleets.

In view of the more recent capacitor related NIRs on other train fleets, Bombardier has written to the Voyager traction equipment supplier (Alstom) seeking clarification whether any other capacitors within the propulsion case of the CVS require additional safeguards along with the supporting engineering justification. Should anything further arise from this enquiry, you will be notified accordingly.

C2C Rail Ltd

11. We have asked C2C Rail Ltd to inform us if any actions had been identified by the review being carried out by Bombardier and if so, how they were being addressed.

12. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, C2C Rail Ltd has:

- taken the recommendation into consideration; and
- is taking action to implement it, but ORR has yet to be provided with a timebound plan.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

13. In its response on 3 July 2018 c2c Rail Ltd stated:

Trenitalia c2c Ltd operate 74 class 357 emu's and 6 class 387 emu's which are Bombardier built Electrostars. All of these vehicles are leased to c2c and are maintained by Bombardier at East Ham Depot. Bombardier have taken the recommendation from the RAIB report and are currently reviewing the design of the electric traction systems on the entire Electrostar fleet to ensure that there are adequate safeguards in place to prevent an explosion capable of causing harm in the event of a capacitor failure. Bombardier have not yet concluded their review and provided Trenitalia c2c Ltd.

Chiltern Railways Ltd

14. Chiltern Railways, following consultation with the owners of the Class 68 fleet they operate (DRS), have concluded that a failed capacitor would be contained by the equipment case which is located within the body of the locomotive rather than in an underframe. See para 82 for more information.

15. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Chiltern Railways Ltd has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation.

Information in support of ORR decision

16. In its response on 3 July 2018 Chiltern Railways stated:

For Chiltern Railways, this recommendation is only applicable to our diesel-electric locomotives, a very small portion of Chiltern Railways' overall fleet. The majority of Chiltern Railways' fleets are Diesel Multiple Units that have diesel-hydrodynamic and diesel-mechanical drive trains with no electric traction or large capacitors.

The class 68 locomotives have capacitors for smoothing DC currents in the traction circuits. These are contained in sealed equipment cases in the locomotive in the clean air compartments (not directly accessible from the cabs) thus passengers and members of the public are highly unlikely to be exposed to them and traincrew are unlikely to be exposed to them when the locomotive is in use. Maintenance staff do not work on live electrical equipment and have the same exposure risk as traincrew.

Chiltern Railways therefore believe that the designs of all its fleet do not present a risk of harm from explosion due to capacitor failure.

We have also been communicating with DRS about this issue, through whom Chiltern lease its class 68 fleet. DRS have confirmed that they have also concluded that these locomotives pose minimal risk in relation to this issue of capacitor failure and have advised that this has been substantiated further in their direct response to you.

East Midlands Trains

17. East Midlands Trains (EMT) identified no issues with Class 153, 156, 158 and HSTs as they do not have large capacitors. Bombardier are reviewing the traction system on the Class 222, together with the similar Class 220/221 fleets, taking account of previously mentioned NIRs. EMT will decide on what actions to take following the conclusion of the Bombardier investigation.

18. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, East Midlands Trains Ltd has:

- taken the recommendation into consideration; and
- is taking action to implement it through discussion with the manufacturer of the Class 222 fleet

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

19. In its response on 18 March 2019 East Midlands Trains stated:

Following the RAIB report 05/2018 with reference to the underframe explosion concerning a traction capacitor on a Class 455 unit.

Class 153, 156 and 158

The Class 15x units have a mechanical transmission and hence there are no traction capacitors fitted to these units.

HST

There are no large traction capacitors fitted on the HST Power Cars. Within the traction system the only capacitors are small snubber capacitors that are fitted across the diodes in the rectifier bank. The rectifier is located within the clean air compartment of the power car and is housed in a steel case which would retain any failure.

There are no traction capacitors fitted to the HST trailer cars.

Class 222

Bombardier have undertaken a review of the traction systems on the Class 222 units as there are several large capacitors associated traction electronics. The review has also taken into consideration NIR reports 1624, 2000 and 2624. The initial report concluded that easy burst covers needed to be considered for the CVS case which is fitted to the underframe of the vehicle. Bombardier are now carrying out a more detailed risk assessment of this area and their final report will be issued by the end of April. All traction capacitors on these vehicles are mounted in cases on the underframe of the vehicle.

New Build

In the current East Midlands franchise there are currently no plans to change the rolling stock as listed above. As you will be aware the East Midlands Franchise is currently being let and the prospectus details that there will be new rolling stock required. It will be up to the new franchise team to ensure that any new or cascaded rolling stock take into account the recommendations of the RAIB report.

Eurostar

20. We have asked Eurostar to provide details of any actions identified as a result of their investigation into the capacitors on Class 373 and 374 trains.

21. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Eurostar has:

- taken the recommendation into consideration; and
- is taking action to implement it, but ORR has yet to be provided with a timebound action plan.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

22. In its response on 28 June 2018 Eurostar stated:

Eurostar International Limited currently operates two fleets of trains, Class 373 and Class 374. I shall deal with these separately below.

Class 373 trains were introduced to passenger service in 1994 and comprise two power cars with 18 intermediate vehicles. They are high speed trains, approximately 400m long and designed to operate at 300km/h and are used on services between London and Paris / Brussels / South of France.

One of these trains experienced an explosion on board a power car while in Temple Mills Depot, near to Stratford in east London on 21st May 2018. Our initial investigation reveals that this incident appears similar to the incident in Guildford, albeit with less serious damage (all components being contained within the affected power car).

The capacitor involved relates to the 500v DC Train Auxiliary Chopper (TAC) and was of a similar polypropylene dielectric design to that involved at Guildford, albeit supplied by a different manufacturer. The capacitor involved had been newly installed and the train was being powered up for the first time following fitment. Within 3 minutes of this happening a loud bang was heard from the power car and the depot filled with smoke. The fire services attended and extinguished a small fire within the power car. No one was present in the power car at the time, nor in the vicinity (the train being powered up from the opposite end driving cab) and there were no injuries.

Initial investigation revealed blast damage with damage to panels, however this was contained aboard the train.

Initial investigation of the capacitor suggests that this degraded quickly, releasing gasses into the power car which were then ignited as contactors operated as part of the process of powering the train up.

We have engaged external assistance in undertaking the investigation from SNC Lavallin and are considering the recommendation and learning points contained within the Guildford Investigation report as part of this process.

We have not previously experienced such an explosion involving TAC capacitors in the past, which combined with the nature of this event occurring so quickly post installation, satisfies us that we do not have an immediate risk to operations from the continued use of these trains in service. We have however revised our safe systems of work should it become necessary to replace one of these capacitors to ensure the train is powered up in a safe area and that no-one is in or near the power car when this happens.

This investigation will also determine any other capacitors on board the trains which may be affected by similar risks and determine any mitigating action required. The report will be complete and recommendations reviewed by 31st October 2018 after which an action plan will be developed and implemented as required.

Class 374 trains were introduced to passenger service in November 2015 and comprise 16 vehicles in an Electric Multiple Unit configuration where traction equipment, transformers, etc. are located beneath floor level and distributed along the train. They are high speed trains, approximately 400m long, designed to operate at 320km/h and are used on services between London and Paris / Brussels / Amsterdam. They are also approved for use on services to the South of France.

These trains were supplied new by Siemens who we have asked to undertake a review as described within the RAIB's investigation report and to produce details of any mitigating actions which may be required. This report will also be complete and reviewed by 31st October 2018.

I will write to you further by 30th November 2018 containing details of any actions which may be required to fully address the risk of explosion on both class 373 and class 374 trains.

Govia Thameslink Railway Ltd

23. We have asked GTR to notify us of any actions identified from their discussions with the manufacturers and ROSCOs regarding the design of capacitors on their existing Class 700 and future Class 717 fleets. We are satisfied with the conclusions GTR have reached regarding the other fleets.

24. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Govia Thameslink Railway Ltd has:

- taken the recommendation into consideration; and
- is taking action to implement it, but ORR has yet to be provided with a timebound plan for any actions identified from discussions with the vehicle manufacturers and ROSCOs.

Status: *Progressing*. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

25. In its response on 4 July 2018 Govia Thameslink Railway stated:

GTR operate four fleets in service which have traction systems containing capacitors; Class 377, 387 (Electrostar);

These fleets all have traction of the same variant, since introduction in 2003, there are 295 of these trains leased by GTR.

These capacitors are in the Auxiliary Converter Module (ACM), Line Converter Module (LCM) and Motor Converter Module (MCM). All of these modules have their own supervision board linked by fibre optic to the main train management system, MITRAC.

There are twenty fault events which identify capacitor related issues, all of which inhibit the traction system from operating, powering down the inverter and discharging the capacitors.

The capacitors are replaced on planned maintenance every 14 years (B7 exam).

As the capacitors are replaced and to assure ourselves further, GTR and Porterbrook have asked the supplier of the traction equipment; VAPPC, which is part of Bombardier some further questions on the design of the capacitor itself.

- *Do the Capacitors installed in the Electrostar incorporate over pressure detection?*
- *Is this a pressure switch or an overpressure membrane?*
- *If an over pressure membrane, how does this operate?*

GTR will await the Bombardier response on UK Electrostar fleets and follow up with

ORR.

Class 365;

GTR operate 19 Class 365 units, which have been in operation since 1995. These units have pressure relief fitted to the capacitors, when activated the traction system on that vehicle is inhibited until the capacitor is replaced. The pressure relief switch is non- resettable. No further action proposed.

Class 313;

The Class 313/1 fleet which operates on Great Northern has capacitors fitted in the rectifier case on the transformer vehicle. These have been in operation on the fleet for 42 years with issues relating to catastrophic failure. These capacitors have pressure switches fitted. If the capacitor blows the switch short circuits and drops the pan.

This fleet is due to be replaced within 12 months. No further action proposed.

Class 700;

In mid-May GTR wrote to Siemens for a review of the capacitor design on the traction system on Desiro City trains against the RAIB report. To date no response has been received, the responsible Siemens engineer is on leave currently.

As well as these fleets, GTR are about to take delivery of Class 717.

These are the same design as Class 700 which is the Desiro City family. The project team has also followed up on the request made on Class 700 as a part of the Class 717 project assurance. The statement from Siemens is "Siemens PD LD TD have been using polypropylene capacitors for more than 20 years. In the product line TBK/KU (best translated as: Traction kit / compact inverter) used in Desiro City and other units one single failure happened to date with about 10 thousand capacitors are in service with a total of 375 million operating hours. The only failure that happened resulted in a short of the capacitor and the failure was confined to the traction container."

I have spoken with colleagues at South Western Railway in relation to Class 707, similar to GTR, they are awaiting a formal response from Siemens. A date of 31st July has been given for a formal response, GTR will await this response and follow up with ORR.

26. On 28 February 2019, GTR provided the following update in regarding the Electrostar fleet:

*Last week Bombardier completed and delivered a technical report on the capacitors used across the Electrostar platform, please find this report attached - 3EEC200007-2582. The report reviews all equipment used in equipment and concludes that *all large Electrostar film capacitors are fitted with 'pressure relief' devices, and in the majority of installations are mounted in a separate IP 54 enclosure with no additional source of ignition. i.e. only in conjunction with a resistor, inductor or other inert device. This was**

considered to be a safer way to mitigate explosion risk, than relying on pressure switches or explosive gas detection devices bearing in mind the low failure rate of the capacitors if manufactured correctly and adequately rated for the duty-cycle.

Grand Central Railway Ltd

27. Grand Central do not operate trains with electric traction or other vehicles with large capacitors, so the recommendation is not applicable to them.

28. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Grand Central Railway Ltd has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation.

Information in support of ORR decision

29. In its response on 2 May 2018 Grand Central Railway stated:

We have reviewed the report and note the recommendation that RAIB have made. However, as Grand Central only operate Class 180 DMUs, which have a diesel-mechanical rather than electric traction system, we believe that the recommendation is not relevant to our fleet.

Greater Anglia Ltd

30. We have asked Greater Anglia Ltd for an update on any actions being taken with the Class 379 fleet that was identified in their initial response.

31. We have also asked Greater Anglia Ltd to explain the justification for the decision to not make any changes to the capacitors on Class 360 units before they are scrapped or replaced.

32. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Greater Anglia Ltd has:

- taken the recommendation into consideration; and
- is taking action to implement it, but ORR has yet to be provided with a timebound plan.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

33. In its response on 28 June 2018 Greater Anglia stated:

In response to your letter dated 25 April 2018 regarding the RAIB report into the underframe equipment case explosion at Guildford station, here at Greater Anglia we have taken this matter extremely seriously and have therefore, in line with the RAIB's recommendations, conducted a full review of our fleet and the findings are detailed below. The results have been grouped by fleet type for ease.

Class 15x

The Class 15x Diesel Multiple Units do not feature any substantial capacitors and are, as such, not deemed to be of risk to either customers or staff. No further action is to be taken on this fleet.

Class 170

The Class 170 Diesel Multiple Units are our most modern DMUs and feature a more sophisticated battery charging system than the 15x fleet. Upon review, there is deemed to be very little risk of explosion or risk of harm based on the function of and history of this system. In the unlikely event, however, of a catastrophic failure occurring, the battery charging case features secondary retention systems which would prevent any loose debris being released. No further action is to be taken on this fleet.

Class 90 Locomotive /Mk3 Coach /Class 82 DVT Intercity Set

Our investigation into these fleets was focussed on the Class 90 locomotives. There are no large traction capacitors on this fleet or any capacitors which are deemed to be a risk to customers or staff. No further action is to be taken on this fleet.

Class 317 and Class 321 (legacy i.e. DC traction)

These two classes of vehicle have DC traction systems (differing from AC traction below) and therefore do not employ any large capacitors in their operation. Whilst some capacitors do exist in their design, there are none which are deemed to be of sufficient size to cause concern. No further action is to be taken on this fleet.

Class 317 Demonstrator (317 722 – AC Traction)

This one-off unit was fitted with an AC traction package as a proof of concept for the life extension of the 317 fleet. This unit is no longer in traffic and has recently been used as a spares unit with no plans at present to re-introduce it into traffic. It is not therefore seen that this unit will introduce any risk to customers or staff. No further action is to be taken on this fleet.

Class 360

These Siemens-built units are fitted with EPCOS B25650-D1758-A004 Capacitors as per all other "Classic Desiro" EMUs. These are contained within the Traction Control Unit (TCU). During the 15 years' service across all units of this platform (over 1000 capacitors) there have been no failures and, as such, the expert Siemens team have advised that no further action will be necessary.

To ensure staff safety during maintenance, it is mandated that the DC link is earthed and 5 minutes elapsed before proceeding beyond any TCU container covers to ensure that all residual voltages have been discharged. No further action is to be taken on this fleet.

Class 379

The Bombardier (BT) Class 379s differ from previous builds of Electrostar (E) with the design of the electrical cases housing their traction capacitors. This case features a relocated capacitor (on the rear vice front) and a pointed base allowing any moisture to build away from the capacitor. This prevents the possibility of moisture damage.*

The case also has a Perspex cover and secondary outer casing retention to prevent the outer casing from becoming completely detached from the train; another difference from previous E builds.*

In addition, BT has tasked PPC at Derby with reviewing the design of the electrical traction systems, ensuring adequate safety in place in the event of a capacitor explosion. PPC have been requested to report the findings of their investigation by 30/06/2018. This will be reported to the BT E Product Safety Team Manager.*

Class 321 Renatus (Kiepe Electric AC Traction Upgrade)

As part of the Eversholt Class 321 life-extension Renatus initiative, the traction package was upgraded, using the latest control electronics and AC traction motors. This is a similar package to that used on the Class 455s involved in the incident at Guildford.

Immediate action was taken to develop a modification to prevent any such explosion occurring on the '321s'. The modification involves the retrofit of pressure switches to the fabricated tank assemblies of Electronicon type 52 and 53 film capacitors as used in the DC link application of the upgraded traction equipment.

The normally closed contact of the pressure switch is used, opening when an internal capacitor pressure in excess of 0.5 bar is detected. Updated software (versions BE onwards) monitors each thermistor circuit, interpreting an open circuit as a capacitor over-pressure event. This then causes the DC link concerned to be de-energised and locked out. This can only be reset by a maintenance laptop PC.

This therefore provides suitable protection against any such capacitor explosions occurring in future.

Great Western Railway Ltd

34. GWR have identified no issues regarding this recommendation with HST and existing DMU fleets. The traction systems on Class 387s are being reviewed by Bombardier and GWR will act upon any identified actions as necessary. We are satisfied that suitable protection measures are in place for Class 800 and 802 fleets.

35. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, GWR Ltd has:

- taken the recommendation into consideration; and

- is taking action to implement it, but is in the process of discussing the implications of the recommendations with the manufacturer of their rolling stock.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

36. In its response on 18 March 2019 GWR Ltd stated:

GWR have reviewed the contents of NIR 3296 and the subsequent RAIB investigation. Until recently GWR have operated a predominately diesel fleet consisting of second generation DMUs and HST some of which remain in use. These diesel fleets no contain a number of very small capacitors in the control equipment which do not present any risk of explosion if a failure was to occur but would result in a loss of functionality of individual equipment which is designed as part of an established fail safe system and detected ether by the user during maintenance. All such components are contained in well ventilated enclosures.

The recent introduction of electrification on the Great Western Mainline and the operation of Class 387 Electrostar EMUs built by Bombardier and Class 800 and 802 IET's built and maintained by Hitachi. We reviewed NIR 3296 and comment more specifically for these two fleet below.

Class 387 Electrostars.

Consultation with Bombardier and the vehicle owners (Porterbrook) has been established that there have been no similar occurrences of capacitor failures in the 20 years that Electrostar vehicles have been in service. The capacitors used are of a different type to those which are the subject of the NIR. However, it is acknowledged that there is a potential risk of a failure a occurring but it is considered as low risk due to the fact that the enclosures are fitted with pressure relief valves to prevent the build-up of gas pressure. Therefore, should a capacitor begin to degrade then any gas would be escape harmlessly and be detected through visual inspection on maintenance exams. Additionally, they are predominately located in separate IP54 enclosures where there is no source of ignition from equipment such as switchgear. Bombardier have identified five areas of potential concern on Electrostar EMUs as having a level of risk worthy of further consideration due to the presence of large film capacitors in sealed cases with lock-and-hinge arrangements, in most cases compounded by the proximity of potential ignition sources. Two of these risks affect the class 387 fleet. GWR will continue to work with Bombardier and Porterbrook to review these potential risks and make improvements as necessary.

Hitachi Class 800 and 802

Hitachi reviewed the NIR prior to the introduction of these fleets into passenger service as part of the compilation of the Technical File and concluded that due to the different construction of the Japanese capacitors which are made up of individual capacitors formed in a honeycomb arrangement that there is no risk of similar

failures occurring. Should individual failures occur the arrangement is 'self-healing'. These capacitors have been the Hitachi standard for a number of years with many hours of operation on rail vehicles worldwide. Additionally, since the RAIB report was published, further improvements have been implemented with individual capacitors for reliability reasons. For these failures, neither the effects of heating have been observed also heating and gassing have not been repeated on any Hitachi traction design when under test. GWR support the OEM view from Hitachi that the difference in construction is far different to that of the design of the Class 455 (the subject of NIR 3296) and that improved design has further improved the safety and reliability of these traction packages.

In conclusion GWR are content that risks due to capacitor failures remain ALARP for all applicable fleets and will continue to work with our suppliers to ensure that further improvements that become available are considered, GWR will also be reviewing any changes to the information which support these conclusions.

Heathrow Express

37. Heathrow Express have reported that the existing risk controls in place on Class 332 units would contain a capacitor explosion, so no further action is being taken.

38. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Heathrow Express Ltd has:

- taken the recommendation into consideration; and
- concluded that no further action is necessary

Status: Non-Implementation

Information in support of ORR decision

39. In its response on 5 February 2019 Heathrow Express stated:

With reference to the above I can advise that Siemens reviewed this issue on our behalf, and having examined the issue advised us of the following:-

The RAIB report described a failure of the power capacitor's internal self-healing process. This can occur if the polypropylene film is damaged or aged by heat and voltage. As a result this process can lead to pyrolysis of the polypropylene film and cause flammable gases. The RAIB identified six previous failures of capacitors from records held on the NIR system. The reported failures are a summary of different technologies (electrolytic and film capacitors) and diverse root causes like assembly faults, overheating and production.

The RAIB points out that there are three main safeguards available to prevent an explosion caused by gas released from a failing capacitor. However, the reliability of the safeguard systems and their influence on the operational availability was not evaluated in this report. Siemens MO RS TD has field experience with polypropylene power film capacitors for more than 20 years in operation. Up to now Siemens estimates the risk of film capacitor failures as very low and acceptable.

Siemens MO RS TD recommends to follow the operation and maintenance manual supplied with every Siemens rail product. In case of noticeable problems with power capacitors please immediately turn to the contact address specified in the operation and maintenance manual.

The present Siemens traction inverter design in combination with a sophisticated diagnostic system and a careful capacitor layout ensures that even serious capacitor failures are limited to the enclosure formed by the inverter cabinet. So, there is no actual need for further safeguarding measures.

Nevertheless the incident in Guildford gives reason for further investigations in film capacitors, therefore Siemens MO has started an initiative to evaluate the remaining risks in detail. If we identify potential safety improvements during this initiative, we will update this advisory.

Heathrow Express have taken due cognisance of this advice and are maintaining the relevant dialogue with Siemens in respect of any changes to this position.

London North Eastern Railway Ltd

40. We are satisfied that no further action is necessary for Class 91 and 43 fleets. We asked LNER for details of the protection systems and detection systems to prevent a capacitor explosion in place on the new Azuma train fleet. After discussions with the train manufacturer (Hitachi), LNER have confirmed that existing controls are appropriate to prevent an explosion similar to that at Guildford.

41. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, LNER has:

- taken the recommendation into consideration; and
- concluded that no further action is necessary

Status: Non-Implementation

Information in support of ORR decision

42. In its response of 8 February 2019 LNER stated:

We made response to NIR 3296 Class 455 AC Traction Pack Capacitor Failure (08/10/16) which was updated to include the issues of the Guildford incident. Both

instances were caused by defectively manufactured capacitors of a type not used on the LNER fleet.

NIR 3479 Capacitor explosion resulting in fire (24/05/18) was also responded to following a review that identified we do not use the same capacitor arrangements as the Class 373 units and all power circuit capacitors are located within the vehicles body or underframe cases and not in any passenger area.

We reviewed the Guildford report in March 2018. There was only one recommendation in the report and six learning points. We reviewed the design of the traction systems of the Class 225 and HST fleets and identified only two capacitors in the locos and one in the coach underframe that required further investigation.

The Class 91 field supply capacitor and Class 43 main rectifier capacitor are located in cabinets in the equipment bay and engine room. In operation there are no persons present in these areas and they are away from the passenger areas. It was identified low risk for failure of these and no further action was proposed. Maximo records have identified work arising tasks called up to replace capacitors following visual VMI checks.

Mk3 and Mk4 coaches have underframe mounted static converters which have input capacitors. These are mounted inside the converter in fully enclosed compartments on the underframe. Failure of these capacitors would be contained within the enclosure and hence the risk from explosion is identified as low and no further action is proposed.

LNER note the six learning points and can demonstrate compliance with these by example

1 – Failure of Umbrako bolts – investigation into failure of a bolt identified a potential issue with the manufacture and all applications for that manufacturers bolts on the fleet were investigated.

2/3/4 – LNER and Hitachi have been working together to produce hazard logs and hazard IDs for the Azuma fleet. These are being updated and handed over from design to operation and are maintained as a dynamic suite of documents, updated as more experience of the fleet is gained.

5 – LNER review open NIRs on a period basis and aim to update with full close out detail as soon as reasonably practical. Clyx can be reviewed for LNER response times.

6 – LNER have discussed this with Hitachi to ensure that the Azuma trains have been similarly reviewed in line with the work done for the legacy fleet. Hitachi (Chief Operations Engineer now Director of Service and Maintenance Engineering) confirmed in April 2018 that the only power capacitors on the fleet were located in the underframe and any catastrophic failure would be contained by the vehicle floor and underframe compartments. There would be no risk to passengers or crew and hence further mitigation was not considered necessary.

43. On 12 March 2019 LNER provided the following update:

Hitachi have confirmed that the failure mode described in the Guilford incident is not credible for the design of capacitor used on the Class 800 fleet and therefore there is no further detection or protection systems required.

Could you please confirm that this is adequate to close out for our AT300 fleet?

Hull Trains Ltd

44. Hull Trains do not have any existing rolling that this recommendation is relevant to, but are discussing the possible implications with the manufacturer of their new rolling stock, which will be delivered later in 2019

45. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Hull Trains Ltd has:

- taken the recommendation into consideration; and
- is taking action to implement it, but is in the process of discussing the implications of the recommendations with the manufacturer of their new rolling stock.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

46. In its response on 26 February 2019 Hull Trains stated:

I have discussed the RAIB report alongside the other professional heads within Hull Trains and at this time we are satisfied that the recommendations listed within the report (05/2018) do not apply to Hull Trains as we have a purely mechanical traction system that doesn't have these components.

The electrical supply on board our trains is also of a different type and doesn't operate in this way nor would it have the same components.

However, we do note that we will be taking delivery of 5 class 802 bi-mode units in 04 of 2019. In conjunction with the vehicle designers Hitachi we will be making them aware of the content of this report and the recommendations arising from it. We will be taking steps to assure ourselves from the information supplied to us from Hitachi that appropriate engineering safeguards are in place during the build phase to prevent a capacitor failure which could potentially result in a potentially harmful explosion.

Merseyrail

47. The recommendation is not applicable to Merseyrail's existing Class 507/508 fleets. Merseyrail have discussed the recommendation and learning points with the manufacturer of their new rolling stock and concluded that the capacitors used would not release sufficient gas to cause an explosion if they failed during operation.

48. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Merseyrail Ltd has:

- taken the recommendation into consideration; and
- concluded it that no further action is necessary

Status: Non-Implementation

49. In its response on 3 July 2018 Merseyrail stated:

The components in question are not of a type fitted to the Class 507/508 fleet and therefore after review it was assessed as not being applicable to our fleet. The recommendations and learning points however are being built into the design of the new fleet.

50. On 28 February 2019 Merseyrail provided the following update:

20 ABB statement on RAIB 052018

Here below it is summarized the statement from ABB on the measures taken for the converter design to avoid future incidents related to capacitor explosions:

The traction converter for Mersey rail is designed according relevant standards. The converter is based on the field proven air-cooled BORDLINE CC DC product family. Over 300 units are in the field since 2011 with no single explosion and no anomalies in the factory tests.

As for all BORDLINE CC products a 100% production testing is forseen also for Mersey rail project. Each shipped converter unit will undergo the 4 hour burn in test in order to detect potential manufacturing defects.

Compared to the „Guildford-Kiepe-design“, ABB is using a different type of capacitor with significantly smaller physical units (Kiepe=11.0 mF, ABB=1.4 mF or 0.4 mF). In case there would be a (not detected) production quality issue, the amount of gas emitted would be significantly smaller.

MTR Crossrail

51. Following their initial response, we asked MTR Crossrail to confirm if there is any protection or fault detection on the capacitors in the Class 345 fleet. MTR Crossrail have explained the prevention measures they have in place and we are satisfied that no further action is necessary regarding the Class 345 fleet.

52. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, MTR Crossrail Ltd has:

- taken the recommendation into consideration; and
- concluded that existing safeguards on capacitors are sufficient

Status: Non-Implementation

Information in support of ORR decision

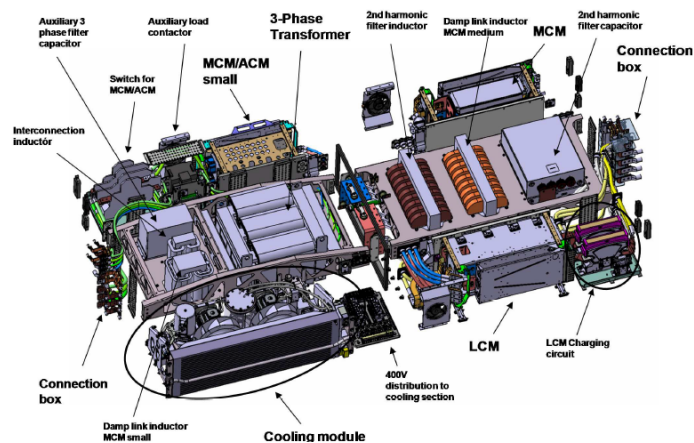
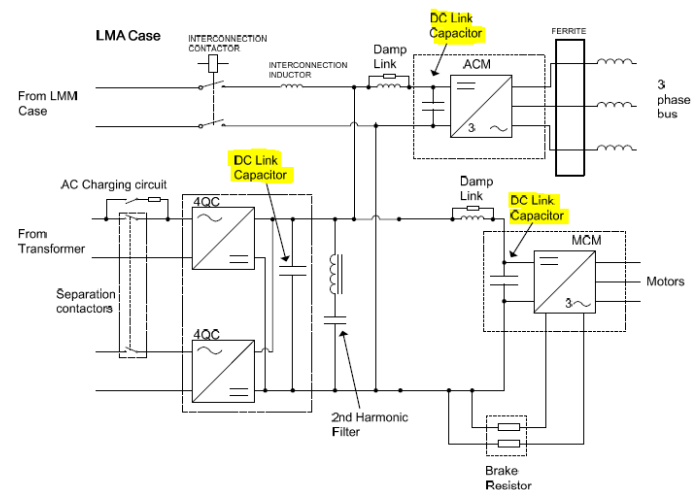
53. In its response on 20 July 2018 MTR Crossrail stated:

This document is intended to determine whether each of the fleets operated by MTR Crossrail is equipped with ventilated equipment cases and identifies credible sources of ignition. Each fleet is discussed in isolation.

Class 345 Review

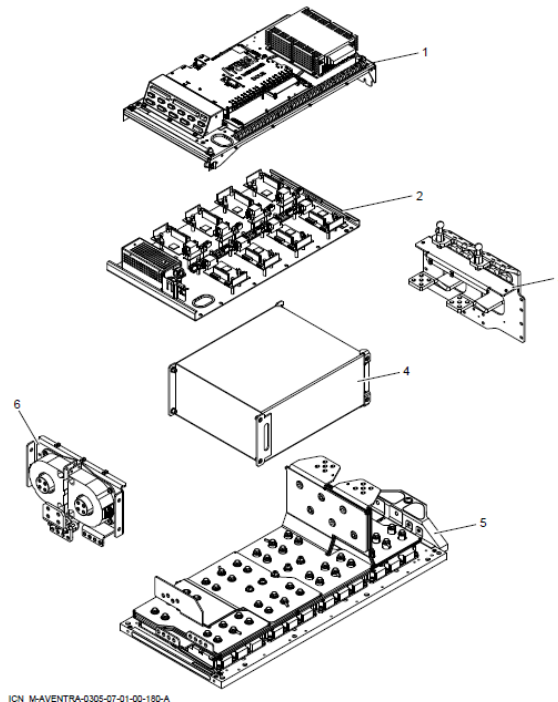
Class 345 takes an output of the main AC transformer and 'rectifies' to DC current using the Line Converter Module (LCM). The output rails are commonly known as the 'DC link' that is subsequently inverted by the motor or auxiliary converter modules (MCM & ACM). Class 345 have DC provision indicating they can retrospectively be modified to operate on third rail infrastructure.

DC link capacitors are installed on the output of the LCM and on the input terminals of the ACM and MCM modules. A second harmonic passive LR filter is installed that has a contributing effect on capacitance.



MCM, LCM & ACM module review

The above diagram identifies 4 as the DC link capacitor in the sealed MCM module. A review of the functional description determines that the capacitor is 'self-healing with segmented metallization using metallized polypropylene' with no contactors within the case.



Mechanical separation and charging contactors are notably installed outside the sealed module.

Converter Enclosure

The enclosures are made up of aluminium. The enclosure holding the MCM, MCM-M and LCM is designed for class IP65 in accordance with EN60529. This ensures that:

- Parts in the enclosure cannot be accessed from outside.
- Dust is prevented from entering.
- Water jets from any direction does not cause any damage.

Cooling of solid state components is achieved by a water cooled closed loop system. The heat exchanger exhaust air is used to cool the magnetic components mounted in the central section of the converter case.

Class 315 Review

Class 315 traction equipment does not rely upon rectification of AC current to DC but uses phase angle control. Traction cases are all naturally ventilated and no DC link is adopted in the design.

Conclusion

MTR Crossrail has determined for CL345:

- *The capacitor manufacture is different to that identified in the RAIB report;*
- *DC link capacitors are contained within the IP65 environment;*
- *Sources of ignition are outside the IP65 environment*
- *Second harmonic capacitor (contributing to capacitive element) force air cooled.*
- *Low voltage ignition sources are contained in the cooling module.*

MTR Crossrail has further determined for CL315:

- *Traction cases are naturally ventilated thus explosive gasses would be dispersed upon production;*
- *No DC link – phase angle control.*

It has been determined that CL345 or CL315 offer any credible failure mode that would lead to the events set out in RAIB report 05/2018.

54. MTR Crossrail provided the following update on 28 February 2019:

With regard to the Class 345 fleet - No pressure sensing equipment is present since there are no sources of ignition (contactor) in the case local to the capacitors to ignite what flammable gasses may have accumulated. Should the capacitor not self-heal sufficiently, the traction package would be isolated. Either way, the presence of pressure sensing equipment would serve no benefit.

Northern Rail Ltd

55. We have asked Northern Rail Ltd to notify us of any actions identified from their discussions with the manufacturers and ROSCOs regarding the design of capacitors on their existing and future fleets.

56. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Northern Rail Ltd has:

- taken the recommendation into consideration; and
- is taking action to implement it, but has not yet provided ORR with full details of actions being taken in response to the recommendation.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

57. In its response on 3 September 2018 Northern Rail stated:

Previous to the incident an NIR 3296, was issued to the industry by the operator on 10th October 2016. The NIR detailed the failure of a power capacitor post traction upgrade on a Class 455 unit operating on 750 DC supply voltage. The NIR was

subsequently updated following the uncontained failure of a power capacitor at Guildford that lead to RAIB investigation.

Northern operate legacy electric rolling stock within the current franchise that by design have capacitor provision. In response to the ORR requirement, Northern have engaged with our rolling stock leasing companies and the following position has been established:

Porterbrook

319 fleet – 33 units operated, 25kv OHL provision [750dc supply isolated], traction via DC motor package

323 fleet – 17 units operated, 25kv OHL provision, traction via AC motor package

Porterbrook have provided analysis on both fleets and the capacitor protection installed. A pressure protection system is present on both fleets. Activation of these devices inhibits the traction current. There are no known capacitor failures in these fleets that have resulted in an explosive event. The 319 fleet has been operated a relatively short period of time within the franchise. Maintenance provision is in place to examine and check installed capacitors as well as equipment case integrity.

The 323 fleet has recently undergone a retraction package that replaced a number of aging capacitors.

No further action is proposed on 319 and 323 units based upon the information provided to Northern.

Eversholt Rails

321 fleet – 3 units operated, 25kv OHL provision, traction via DC motor package

322 fleet – 5 units operated, 25kv OHL provision, traction via DC motor package

Eversholt Rails have provided information on both fleets [321/322 traction package is identical] and the capacitor protection installed. Current monitoring devices are installed on line capacitors on the fleet that inhibit traction current. Eversholt Rails internal risk assessment classes the 321/2 fleet as ALARP. Northern have no experience of capacitor failure in the vehicles operated. Maintenance provision is in place to examine and check installed capacitors as well as equipment case integrity.

Of note Northern do not operate the AC retraction 321 units known as 'Renatus'.

No further immediate action is planned on these fleets. Northern will continue in dialogue with Eversholt Rails on the continued development of capacitor risk assessment.

Angel Trains

333 fleet – 16 units operated, 25kv OHL provision, traction via AC motor package

Angel trains (ATL) have provided information on the capacitor type fitted and the on board management of these components. At present this work is not complete by ATL and further dialogue is required. The 333 fleet is maintained under contract by Siemens and is subject to their own internal safety management as well as Northern's. There is a structured maintenance regime in place and no known failures of capacitors similar to the Guildford incident have been recorded.

Northern continue to work with ATL to develop a full understanding of any potential risk from capacitor failure. Actions determined as required will be communicated to the ORR if deemed significant.

In summary of the Northern EMU fleets in respect of Rec 1 of RAIB Report 05/2018

319 Fleet – no further action and risk contained

321 Fleet – no immediate action and risk is considered ALARP

322 Fleet – no immediate action and risk is considered ALARP

323 Fleet – no further action and risk contained

333 Fleet – on going work with ATL and Siemens to determine any residual risk from the unit design and capacitor arrangement. However, this is currently considered low. Northern will update ORR on any significant change in this position.

Currently Northern are engaged with the introduction of bi-mode and new build rolling stock. Neither of these projects are yet in passenger service and both are entering the test stage on UK infrastructure. Commentary on these two projects is as follows

CI 769 'Flex'

The CI 769 'Flex' project is a Porterbrook lead modification of a base CI 319/4 EMU. The work will install two diesel engines and generator sets that will supply the DC traction package to power when the unit is away from OHL areas of operation. The design has not changed or increased the capacitors currently installed in the traction circuits. The NIR and subsequent RAIB report have been included in HAZOP and project review. This will be fully closed out as the project approaches completion and full consideration given to dynamic testing. Northern will continue this dialogue until a suitable position is achieved with Porterbrook and will update the ORR on any significant change in this position. Entry to service is planned for late 2108.

CI 331 New Build

The CI 331 new build procurement project is a franchise commitment for Arriva within the Northern franchise. There are currently forty-three EMU units in the build, test and commission stage. The builder appointed is CAF, based in Spain. The owner of these units is Eversholt Rails with Northern leasing the units for passenger operation. The design is based upon CAF 'Civity' platform. The traction package is manufactured by CAF Power including all procurement of traction capacitors. The NIR and subsequent RAIB report have been included in HAZOP and project review.

As a consequence dialogue is ongoing with CAF on the selected capacitors installed in the CI 331 project. Evidence supplied to date by CAF has supported the safe use of selected capacitors in this application with the current design placed in several traction applications with no failures reported. Northern will continue this dialogue until a suitable position is achieved with CAF and will update the ORR on any significant change in this position. Entry to service is planned for late 2018.

Northern note the comments on the 'Learning Points' identified in the RAIB report and offer additional information as below.

- 1. Investigation of safety-related incidents are routinely conducted by competent and experienced engineers. The process is documented with Northern SMS and the level of investigation required. If additional contributory factors are identified investigations will include these areas. If subject specialists are required external support will be commissioned as necessary. All investigations are reviewed and authorised by an independent senior manager for completeness and that investigation remit has been met. Any recommendations are tracked within the business till closure via relevant safety forums.*
- 2. Hazard identification and hazard logs are instigated and documented within projects that contain significant change. These are maintained by the project lead and reviewed on a periodic basis. Additionally, engineering change process within Northern includes identification of projects with significant change. Northern note the requirement of Guidance Note GE/GN8642 and will ensure this is contained within this process.*
- 3. As per commentary in point 2.*
- 4. As per commentary in point 2.*
- 5. Northern note comment and endeavour to maintain raised NIR on the register in a timely manner. Full information including relevant reports are shared on concluding statements.*
- 6. Commentary provided on new build and traction upgrades in body of letter.*

ScotRail Ltd

58. We have asked ScotRail to explain the decision to not make any changes to the capacitors on the Class 380 before they are scrapped or replaced. We have also asked for more information around the decision to take no further action with the Class 385 fleet.

59. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, ScotRail Ltd has:

- taken the recommendation into consideration; and
- is taking action to implement it, but has not yet provided ORR with full details of actions being taken in response to the recommendation.

Status: *Progressing*. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Information in support of ORR decision

60. In its response on 30 July 2018 ScotRail stated:

Thank you for your letter with regards the RAIB report into the underframe equipment case explosion at Guildford station. Here at Abellio ScotRail, our customers' safety is paramount and as such we have taken this matter extremely seriously and have therefore, in line with the RAIB's recommendations, conducted a full review of our fleet and the findings are detailed below. The results have been grouped by fleet type for ease.

Classes 314, 318 & 320

These fleets of vehicle have DC traction systems (differing from AC traction below) and therefore do not employ any large capacitors in their operation. Whilst some capacitors do exist in their design, there are none which are deemed to be of sufficient size to cause concern. We have reviewed NIR's with ROSCO's during technical reviews and no further action is to be taken on these fleets as older DC traction is deemed lower risk.

Class 334

We raised a NIR following an incident with a class 334 capacitor on 23rd December 2016, we have worked with Eversholt and Alstom and have replaced the capacitor with an oiled filled capacitor, we have also vented the underframe cases and revised maintenance instructions. As major component overhauls become due we review maintenance content and new products available with ROSCO's. At present no further mitigation action being taken as we will monitor systems and failure modes as part of our processes.

Class 380

Our review with Eversholt and Siemens these units have been in operation since 2010 and there have been no failures of any capacitors and as such the experts from Siemens have advised that the state of the art design and testing process and the product quality shows to be proven in the field for 20 year the risk is low, therefore no further action at present.

Class 385

A review with Hitachi, the design of capacitance system has been the Hitachi standard for a number of years and we believe that the issue seen on the class 455 cannot be repeated on any Hitachi traction design.

In considering the RAIB report of the failure of the traction capacitor on the Class 455, we believe that the difference in construction of the Hitachi capacitors is far different to that of the German design and that we have improved our design to improve the longevity, safety and reliability of the Hitachi traction packages therefore no further action.

Classes 156 & 158

The Class 15x Diesel Multiple Units do not feature any substantial capacitors and are, as such, not deemed to be of risk to either customers or staff. No further action is to be taken on this fleet.

Class 170

The Class 170 Diesel Multiple Units are a modern DMUs and feature a more sophisticated battery charging system than the 15x fleet. Upon review, there is deemed to be very little risk of explosion or risk of harm based on the function of and history of this system. In the unlikely event, however, of a catastrophic failure occurring, the battery charging case features secondary retention systems which would prevent any loose debris being released. No further action is to be taken on this fleet.

I hope this provides a sufficiently comprehensive review of the traction types operated by Abellio ScotRail and the reviews we have undertaken to ensure that such capacitor failures do not occur or are sufficiently mitigated so as to prevent harm to either the paying public or our colleagues.

Serco Caledonian Sleeper Ltd

61. Serco Caledonian Sleeper Ltd, following consultation with the owners of the Class 92 fleet they operate (GBRF), have concluded that a failed capacitor would be contained by the equipment case which is located on the locomotive, rather than an underframe location.

62. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Serco Caledonian Sleeper Ltd has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation

63. In its response of 11 February 2019 Serco Caledonian Sleeper stated:

Caledonian Sleeper do not own or lease any electrical traction. However our sub-Contractor GBRf do supply us with electric traction locomotives to haul our coaching stock. On checking with GBRf they have confirmed that they responded to the ORR with the following which would reflect the Caledonian Sleeper position:

“GBRf do not operate any EMU’s under own power, class 92 has enclosed electronics and class 73/9 has undergone a suitable check and is inspected every exam. We have no such underframe mounted equipment”.

Southeastern

64. We asked Southeastern to provide some more detailed information about the life, risks, degradation and protection system on capacitors on their Electrostar fleet. Regarding the Javelin fleet, we asked what protection systems the capacitors have and how are they deemed to be sufficient. Finally, we asked Southeastern to explain in more detail the decision to take no further action on the BREL/ABB Networker fleet.

65. Southeastern have carried out a detailed review of capacitors on their train fleets in conjunction with the applicable manufacturers and ROSCOs and provided us with an update. Southeastern concluded that existing systems in place are adequate to keep the risk of an incident similar to that at Guildford occurring to a suitably low level.

66. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Southeastern has:

- taken the recommendation into consideration; and
- concluded existing arrangements are sufficient to minimise the risk of a similar incident occurring on one of their vehicles

Status: Non-Implementation

67. In its response on 20 July 2018 Southeastern stated:

Recommendation 1 of the RAIB report suggests that train operators such as LSER to review the design of electric traction systems in their current fleets and check that there are adequate safeguards in place to prevent an explosion capable of causing harm in the event of failure of one or more capacitor(s) and address any shortcomings identified.

LSER operates the following traction types:

- Class 375, 376 and 377 Adtranz/Bombardier Electrostar EMUs
- Class 395 Hitachi Javelin EMUs
- Class 465/0-1 BREL/ABB Networker EMUs
- Class 465/2, 465/9 and 466 Metro-Cammell/GEC-Alstom Networker EMUs

We have reviewed each of these traction types and have concluded as follows:

Electrostar fleet

There is no record of HV capacitors exploding in over 15 years since introduction of this fleet. However if a high speed circuit breaker (HSCB) was required to break a

current of the order of 12000 – 36000A the resulting electrical arc would generated sufficient force to cause the underframe module cover catches to burst and the cover to swing open. Investigation determined that such currents were caused by defective Line Inductors so a decision was made to replace the inductor type to address the root cause.

Notwithstanding this decision it is also proposed to make a lanyard modification to the module covers to keep them within gauge in the event of an explosion of the order of magnitude experienced at Guildford. This modification is scheduled to be completed by March 2019.

Javelin fleet

Hitachi, who maintain the Javelin fleet for LSER, have reviewed the design of the fleet and tested all under-frame modules for gaseous build-up. They have concluded that the design of the Javelin traction system is sufficiently different from that involved at Guildford that the failure mode will not occur on this fleet.

BREL/ABB Networker fleet

These units were fitted with a new Hitachi traction package some 8-10 years ago and this involved removal of side skirts from the units as well as replacement of the underframe modules. The new modules incorporate ventilation wherever possible thus preventing the risk of gaseous build-up. There have been two capacitor failures on this fleet but neither involved a capacitor explosion. LSER therefore believes that the risks on this fleet are sufficiently mitigated.

GEC/Alstom Networker fleet

Expanding gases caused by traction capacitor failure are detected by a pressure switch which cuts off the traction current and removes any source of ignition. In addition equipment module covers are designed to be retained within the side skirts of the vehicle, and there is an air gap between the modules and the side skirts which helps dissipate the energy of any explosion. Over the years that these trains have been in service there have been instances of auxiliary capacitors exploding as a result of manufacturing defects but module covers have always been retained within the side skirts. In view of this, LSER believe that the risks on this fleet are sufficiently mitigated.

To summarise LSER will implement a lanyard modification on its Electrostar fleet, and this is due for completion by March 2019, but does not believe modifications to be necessary on its remaining EMU fleets.

68. Southeastern provided the following update on 2 March 2019:

Class 395

Hitachi have completed a detailed review of their high energy capacitors in response to RAIB report 05/2018 and NIR 3296. The investigation concluded that the capacitors are a different design which are not at risk of this failure mode. The individual capacitors are designed to self-heal in the event of an over-current, minimising gas build-up. In addition, the shell of the capacitor bank cover is a lattice structure, designed to easily fracture to relieve pressure build up in a more controlled manner.

Class 465/0/1

The Hitachi traction package has been fitted for approximately 10 years. The system is running at around 2,000,000 miles mean distance between failure and has one capacitor failure in this time, which was not an explosive event. The Hitachi traction package is a modular raft which consists of a large equipment case and an external resistor grid. This large equipment case has such a volume that any explosive event would likely be contained within the case. Any overpressure would be forced into the circuit breaker compartment and out to atmosphere through the ventilation louvres. This compares to the two smaller cases used on the modified Class 455 involved in the incident investigated by RAIB (as per paragraph 35). The Class 465/0/1 fleet is expected to be withdrawn from traffic within five years, which means that the capacitors will be at a maximum of 15 years old, which is within the lifetime of the system. Southeastern do not believe there is a risk of capacitor degradation in this timeframe, and therefore minimal risk of catastrophic failure of equipment cases as a result of capacitor failure.

Class 465/2/9 and Class 466

This fleet are fitted with pressure switches which cut out the traction current if capacitor failure occurs. This should limit the magnitude of any explosion as a result of capacitor failure. The capacitors are contained within equipment cases that are themselves contained within side skirts, with a significant air gap between them. These skirts are capable of containing the equipment case covers, and the air gap will permit the explosive force to dissipate before reaching the skirts. Having reviewed these measures and previous failure history with Angel Trains, Southeastern are satisfied that there is minimal risk of catastrophic failure of equipment cases as a result of capacitor failure.

Class 375/3/6/7/8/9, Class 376 and Class 377/1/5

Having reviewed failure data with Bombardier as a result of the RAIB report, it was discovered that there had not been a capacitor failure on the Electrostar family nationwide for the almost 20 years the fleet has been in service. All large film capacitors are fitted with pressure switches, and in almost all cases are segregated from potential sources of ignition. There are three equipment cases on Electrostar derivatives which could permit the build-up of flammable gases: The DC link capacitor on Class 376 is located in a separate case isolated from any potential source of ignition; the ACM capacitor is relatively low-power, and is therefore highly

unlikely to ever be loaded to the point of degradation and failure; the AC contactor case does contain a capacitor and a potential source of ignition, but the capacitor is relatively small and in the unlikely event of failure would not release sufficient gas to pose a risk of explosion. These findings, discussed following the publication of the report, have subsequently been formalised in a Bombardier report issued in February 2019.

In conclusion, Southeastern believe that the risk of catastrophic failure of equipment cases as a result of capacitor failure to be minimal on the Electrostar fleet. This is because all large capacitors are fitted with pressure switches, and in almost all cases are segregated from potential sources of ignition. Where this is not the case, the capacitors are highly unlikely to be able to produce sufficient build-up of flammable gases to cause an explosive event.

General comments regarding Southeastern's response to RAIB report 05/2018

Explosion inside an underframe equipment case at Guildford

7 July 2017

The capacitor which failed in the incident in question (the DC link capacitor) had failed seven times in 20 months prior to this incident (twice during manufacturer testing and five times on trains, as per paragraph 56). This far exceeds the failure rate of any high-energy capacitor fitted to any Southeastern fleet. The manufacturer of the capacitor in question only began supplying traction equipment for heavy rail vehicles in 2009 (as per paragraph 86) and were fitted as part of a recent project to change the traction system on a specific fleet.

It is therefore Southeastern's belief that the circumstances which led to this failure are a result of inadequate engineering design, testing and acceptance, not aged components or the failure of established systems with a history of reasonable reliability. This is supported by the causal factors detailed in paragraph 123. Southeastern conclude that the accumulation of flammable gases and subsequent explosion and catastrophic failure of the equipment case (the immediate cause as per paragraph 122) as a result of capacitor failure is a very remote possibility on any fleet operated by Southeastern. As a final level of mitigation, all fleets are either fitted with pressure switches to cut out the traction current in the event of capacitor failure, have capacitors fitted within cases which will prevent the accumulation of flammable gases, or are isolated from potential sources of ignition. The once capacitor which does not have either of these three measures in place is relatively small, and thus unable to produce sufficient gas to present a risk of explosion. These measures should eliminate the possibility of equipment case catastrophic failure even in the event of capacitor failure. No such measures were present in the equipment case housing the capacitor that failed in the incident investigated by the RAIB, despite the failure history of the capacitor type in question.

As a result of the recommendation made in the report, Southeastern have identified a risk of an equipment case cover being dislodged because of the traction high speed circuit breaker (HSCB) tripping as a result of line inverter flashover. Although

the line inductor type in question has been replaced, Southeastern believe the cover could still be dislodged as a result of the HSCB tripping, so are in the process of fitting a lanyard to restrain the cover.

South Western Railway Ltd

69. We have asked South Western Railway Ltd to keep us updated on the actions being taken in relation to the Class 444, 450, 458 and 707 fleets.

70. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, South Western Railway has:

- taken the recommendation into consideration; and
- is taking action to implement it, but has not yet provided ORR with full details of actions being taken in response to the recommendation.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

71. In its response on 29 June 2018 and an update on 18 March 2019 South Western Railway stated:

In reply to your request for a response to the recommendations arising from the RAIB investigation into the above incident, please find below a summary of the SWR information for each fleet. For some of our fleets we are still awaiting additional data, a further response will be sent when available.

Desiro Class 444 and 450

The 444 and 450 fleets will be retained by SWR and operated for the duration of its franchise. The SWR operated 444/450 Desiro fleet has a number of capacitors in the traction system. We have considered how these are operated and maintained with our supplier and leasing company, Angel Trains. We understand that the majority of the capacitors include a built in protection device that acts to isolate the capacitor in the event of a build-up of pressure due to a failure.

Siemens AG is undertaking a review of the Siemens UK fleet, we have seen a draft copy of that review but have raised further questions. We hope to see a final version in August and will respond further on our Desiro fleets at that time.

SWR does not believe that further action is required in relation to the Desiro fleet at this time but will review further when we have more information from Siemens.

SWR Update 18th March 2019

Discussions are ongoing between Siemens AG and Angel Trains and further information will be provided to the ORR when available.

Class 455

The 455 fleet is not retained by SWR for the duration of its franchise, this fleet will operate with SWR for 2 years. Following the incident that led to the investigation report under review, SWT and since then SWR has undertaken a significant amount of work together with Porterbrook the leasing company and Kiepe the traction system supplier to understand and mitigate the failure seen at Guildford. This included a review of the failure mechanism and potential protection and mitigation strategies. As an interim measure, additional physical restraints were fitted to traction equipment cases while a permanent modification to fit pressure switches was developed. The fleet has now been modified to have pressure switches on all ac traction equipment cases.

SWR does not believe that further action is required in relation to the 455 fleet for passenger service, at this time, but we continue to monitor performance of the pressure switch modification. SWR has completed a comprehensive review of the HAZID undertaken following the incident to confirm our modification and other mitigation actions have adequately addressed the risks.

SWR Update – 18th March 2019

SWR is developing a modification to implement a test point for detecting gassing of the capacitor. The purpose of this modification is to ensure safety of maintenance staff – in the event a train returns to depot with a defect it would allow the depot to assess the condition of the capacitor. The testing device will be used based on the fault codes within the traction pack that are indicative of capacitor failure or pressure switch operation.

Class 456

The 456 fleet is not retained by SWR for the duration of its franchise, this fleet will operate with SWR for 2 years. The 456 fleet use polypropylene film for the filter capacitors. We understand from the leasing company Porterbrook that these come with pressure switches which inhibit traction on failure. There is a maintenance regime in place to inspect the capacitor case for signs of failure.

Considering the time that the fleet will operate with SWR, we consider the residual risk to be ALARP and SWR does not believe that further action is required in relation to the 456 fleet at this time. However we will continue to work with Porterbrook regarding the longer term requirements for this fleet.

SWR Update – 18th March 2019

No further updates.

Class 458

The 458 fleet is not retained by SWR for the duration of its franchise, this fleet will operate with SWR for 2 years. SWR has been working with the leasing company, Porterbrook, to understand the design and technical protections in place for the capacitors fitted to the 458 Juniper fleet. The 458 fleet has polypropylene film capacitors. These have been identified as obsolete and the identified suitable replacement capacitor is oil-filled and fitted with a pressure switch. There is currently no routine change out of capacitors planned. SWR has a maintenance regime to regularly inspect the capacitors.

Considering the time that the fleet will operate with SWR, we consider the residual risk to be ALARP and SWR does not believe that further action is required in relation to the 458 fleet at this time. SWR is reviewing the long term plan for the 458 fleet with our leasing company Porterbrook, and the manufacturer Alstom.

SWR update – 18th March 2019

SWR is developing a modification to implement a test point for detecting gassing of the capacitor. The purpose of this modification is to ensure safety of maintenance staff – in the event a train returns to depot with a defect it would allow the depot to assess the condition of the capacitor. The testing device will be used based on the fault codes within the traction pack that are indicative of capacitor failure or pressure switch operation.

Class 707

The 707 fleet is not retained by SWR for the duration of its franchise, this fleet will operate with SWR for 2 years. Siemens AG is undertaking a review of the Siemens UK fleet, we have seen a draft copy of that review but have raised further questions. We hope to see a final version in August and will respond further on our 707 fleet at that time.

SWR Update – 18th March 2019

The Class 707 fleet will not be retained by SWR for the duration of the franchise. Discussions are ongoing between Siemens AG and Angel Trains and further information will be provided to the ORR when available.

Class 442

SWR will introduce a fleet of 442 trains into service from later this year. During 2019 these will be retractioned with equipment similar to that fitted to the 455 fleet. The lessons learnt and mitigations applied to the 455 fleet traction equipment will be applied to the new equipment fitted to the 442 fleet. This will include pressure switches.

SWR Update – 18th March 2019

No further updates.

Virgin Trains

72. We have asked Virgin Trains to provide details of the findings of their investigation into the Voyager fleet, any subsequent actions identified and the timescales for delivering them. We have asked Virgin Trains to provide information regarding actions they took after raising NIR 1635, NIR 2000 and NIR 2624 and to consider liaising with Arriva Cross Country to discuss actions they have taken.

73. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Virgin Trains has:

- taken the recommendation into consideration; and

- is taking action to implement it, but has not yet provided ORR with full details of actions being taken in response to the recommendation.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

74. In its response on 13 July 2018 Virgin Trains stated:

I am writing in response to your letter dated 25th April 2018 in relation to the recommendations contained within the RAIB report as detailed above. West Coast Trains Limited (WCTL, Trading as Virgin Trains) currently operate two different fleets these are CI390 EMU and CI221 DEMU both fleets, and the measures taken have been separated between the two in regards to the proposed recommendations contained within the RAIB report.

Class 390 have a number of capacitors fitted to both the Auxiliary Convertors (five vehicles) and Propulsion Case. The Auxiliary Convertors DC Link Filter Capacitors have pressure switches fitted that will isolate the voltage supply should the internal pressure rise by more than 0.5 bar. The 3-Phase Output Filter Capacitor in the Converter is fitted with an internal overpressure disconnecter mechanism. Where the pressure within the capacitor due to degradation of the polypropylene film will cause the case to deform and the internal wires will act as tear-off fuses which in turn removes the voltage source also. There is an exam task that checks the value of capacitance every 18 months for which if found out of tolerance are replaced. The Propulsion Case has a Tuned Filter Capacitor which is fitted in a ventilated section of the case and therefore has no expansion sensors or pressure switches fitted. There are also DC Link Filter Capacitors mounted in the sealed section of the Propulsion Case again there are no pressure switches for these capacitors however the case is fitted with a heat exchanger and a fan which limits the internal temperature. It must also be noted that these were upgraded after 5 years of service operation with no issues found. A maintenance task will now be present to ensure that the air flows are adequate in this area. A new design of inlet grill is also being evaluated to reduce the risk of blockages which will be implemented in the new regime currently awaiting sign off.

Class 221's previously witnessed a very similar incident within the traction module fitted to the one detailed in the RAIB report notably back in 2003 under NIR1635. Following this incident, the recommendation to retro-fit pressure sensors to detect any gas build up and remove the voltage supply was undertaken. 'Easy-burst' covers were also fitted as an interim measure to release gas whilst still being able to contain any components in the event an explosion.

There had been no further instances of this failure mode until 23rd June 2018. This is when a traction fault was occurred on depot. On investigation the panels of the traction case were found to be expanded and these were removed to discover that the traction module had equally incurred an internal explosion. The traction pack was returned to the OEM and the pressure switches were sent off to ESR for further investigation to understand whether they were operational. The report from ESR was received on the 10th July 2018 which concluded that the pressure switches were in fact operational within the specification. Investigation is currently still ongoing with the OEM, but early indications suggest that although damaged slightly by the

explosion, the small pipe that is fitted to direct any gas to the pressure sensors could have not been fitted correctly and had been pinched/kinked which restricted the gas flow therefore not activating the pressure switches. Containment measures will be put in place by 13th July 2018 and once the investigation is completed and root cause established an NIR will be raised as appropriate.

West Midlands Trains

75. We have not received a response from West Midlands Trains to this recommendation.

76. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, West Midlands Trains has:

- not the recommendation into consideration; and
- has not provided a response setting out how it will be delivered.

Status: Insufficient response. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Colas Rail

77. Colas Rail have appropriate detection and prevention devices fitted to Class 70 locomotives and LORAM C44 rail grinders. No further action is required, so the recommendation is not applicable to them.

78. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Colas Rail Ltd has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation.

79. In its response on 11 June 2018 Colas Rail stated:

Colas Rail Services is an owner and operator of infrastructure maintenance on track machines and freight trains and is not an operator of passenger trains. Colas Rail Services have identified two types of vehicles that we operate with what I think is a similar arrangement of capacitors within the inverter electrical systems – General Electric class 70 locomotives and the LORAM C44 series of rail grinders.

GE Transportation Systems Class 70 locomotives

The capacitors in series with the auxiliary and propulsion inverters in the aux cab are subject to forced ventilation at all times when power is applied to them by Traction

Motor Blower 1 (TMB1). In the rare event that a fault occurred on TMB1, that would log a restrictive incident and shut down the aux and propulsion system. Furthermore, there are safeguards to prevent over restricted airflow to the aux cab; there are pressure sensors either side of the filter that supplies the aux cab and logs incidents should excessive pressure drop occur. These filters are subject to scheduled change well within the capacity of the filter.

Further detail can be found in GEK-114511 Equipment Ventilation, PH37ACmi PowerHaul Series Locomotive; The #1 End Traction Motor (TMB1)/Auxiliary Blower Circuit (Figure 1) provides ventilating air to the front three traction motors, auxiliary cab and Control Area 1 (CA1). The blower for this function is located above the auxiliary cab in the blower compartment. The blower pulls air through perforated v-screens and spin filters for cleaning, then blows the clean air through a duct to the #1 end platform air plenums, which carry the cooling air to the three #1 end traction motors. A portion of the air is directed to the auxiliary panels and CA1 from this duct. A minimum airflow is provided at all times to maintain a positive pressure inside the traction motors and auxiliary cab, thereby minimizing dirt and moisture entry.

LORAM C44 rail grinding machines

The information I have for these machines is a report from LORAM, the equipment manufacturer, which states that the traction system is housed in an enclosure which has a continual positive air pressure supplied to it by 2 air pressurisation units. I have attached the results of the test performed on the pressurisation system on the C44 series machine C4402 for your reference.

Devon & Cornwall Railways

80. We have not received a response from Devon & Cornwall Railways to this recommendation.

81. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Devon & Cornwall Railways has:

- not the recommendation into consideration; and
- has not provided a response setting out how it will be delivered.

Status: Insufficient response. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

Direct Rail Services

82. DRS have reviewed the recommendation and concluded that where they have vehicles with large capacitors they are not mounted in underframes but instead contained with the body of the locomotive, which would contains any explosion.

83. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, DRS has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation.

84. In its response on 2 May 2018 Direct Rail Services Ltd stated:

From reviewing the Recommendations and Learning Points as part of RAIB Report 05/2018, Explosion inside an underframe equipment case at Guildford, 7th July 2017; I do not believe that any action is required from the DRS Engineering Department, the recommendation is applicable but I believe is closed for the following reasons. DRS do have locomotives with AC traction with a DC-DC link, the DC-DC link capacitors are contained within the vehicle body in a cupboard so it is not the same arrangement as in the report and the DRS components are from a different supplier. If a component (i.e. capacitor) was to fail and cause any 'explosion' this would be contained within the vehicle and not able to cause injury due to flying debris as in the RAIB report.

DB Cargo

85. We are satisfied that no action is needed with Class 90 and 92 locomotives. We have asked DB Cargo to provide further justification for the decision to take no further action with the Class 325 fleet and that the existing maintenance plan remains fit for purpose.

86. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, DB Cargo has:

- taken the recommendation into consideration; and
- is taking action to implement it, but has not yet provided ORR with full details of actions being taken in response to the recommendation.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

87. In its response on 25 June 2018 DB Cargo stated:

DB Cargo operates the following electric traction:

Class 90 AC Electric Locomotive (24-off, introduced in 1990)

Class 92 AC Electric Locomotive (17-off, introduced 1996)

Class 325 Electric Multiple Unit (15-off 4-coach units, introduced to service in 1995)

All three vehicles incorporate capacitors within the auxiliary rectifier and surge suppression systems. DBC has completed a fleet survey and reviewed maintenance procedures. The capacitors are located and contained within three types of enclosure. Details of each can be found in Appendix A.

In response to the RAIB recommendations and the ORR letter, DBC can confirm the following with regards to safeguards in place to prevent an explosion:

- None of the capacitors have been changed with regards to design or manufacture, all capacitors are of the original build design and supplied by the OEM.*
- None of the traction systems on the three vehicle designs have been renewed or modified since original build.*
- All casings enclosing the capacitors are sealed but all ventilated ensuring gases from failed components cannot build-up, creating a risk of explosion.*
- All casings are of the original design from vehicle build and have not been altered.*
- The integrity of all casings, electrical circuits and components are inspected in-line with the vehicle maintenance plans at regular intervals.*
- There have be no DBC in-service issues associated with capacitor failures and build of gases reported.*
- No maintenance, High Risk Defect, incidents or reports via the NIR process of issues with capacitors associated with the builds of vehicle stated above have been reported.*
- DBC has no modifications planned for the vehicle types stated above.*
- If a modification to any of the traction equipment, electrical circuits, capacitors or casings was to be implemented, a full 'Engineering Change' process would be followed including a CSM-RA and NIR review. This would be reported within the Technical File for the modification. This is in-line with DBCs SMS and the ECM regulations which are applied to all T & RS.*
- Changes within the OEM supply of electrical components e.g. capacitors or casings would be reviewed as part of the DBCs Procurement process and would result in an engineering review and change.*

DBC takes this issue very seriously and as detailed above will continue to incorporate the recommendations of incidents and high risk defects into 'Engineering Change' process and will continue to monitor the maintenance of the vehicles specified above.

DBC will continue to review and investigate safety related incidents and review and monitor hazard identification and hazard logs as part of the 'Engineering Change' process and in-line with our monitoring processes as detailed within our SMS and the ECM regulations.

In addition to the above, DBC will continue to ensure that any work completed for third party AC traction incorporates appropriate checks to ensure risks detailed within the RAIB report are mitigated.

Freightliner

88. Freightliner have reviewed the recommendation and concluded that it is not applicable to the Class 66, 70, 86 and 90 locomotive fleets they operate.

89. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Freightliner has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation.

90. In its response on 12 June 2018 Freightliner stated:

In accordance with the requirements of RIS-8250-RST Reporting High Risk Defects, Freightliner monitors all NIR and RAIB reports and reviews any that are considered to be potentially applicable to its operations.

Freightliner was initially made aware of incident of this nature on 10th October 2016 via the industry NIR-Online report NIR3296 - Class 455 AC Traction Pack Capacitor. A review was completed at the time using the information available via the NIR-Online report leading to a conclusion that the issue was not applicable to Freightliner's class 66, 70, 86 and 90 locomotive fleets.

On receipt of the RAIB report into the above incident, Freightliner undertook a further thorough review of the circumstances of the failure related to our class 66, 70, 86 and 90 locomotive fleet noting the significant detail provided as a result of the RAIB investigation.

In summary this review of the location and design of the enclosures of capacitors and associated power control equipment revealed all components were either;
a) located in well-ventilated enclosures preventing any build-up of flammable gases or,
b) located in cubicles equipped with forced cooling again preventing any build-up of flammable gases.

In addition a review of service history of the Freightliner locomotive fleets has not identified any failures of this nature affecting these locomotives.

Freightliner has concluded that in the case of an unlikely breakdown of a power capacitor on its locomotive fleet a catastrophic failure of this nature would not occur.

Freightliner has therefore decided that no action is required to modify its locomotive fleet as a result of this incident.

Freightliner also notes the report highlights potential shortcomings in the quality of the Hazard Identification undertaken during the engineering change review for the

modification. This serves as a reminder to all duty holders proposing changes to rolling stock to ensure robust hazard identification is undertaken. It should also be noted that despite the employment of an established independent competent organisation in this case the hazards had not been adequately identified and addressed.

GB Railfreight

91. GB Railfreight have reviewed the recommendation and concluded that it is not applicable to the Class 92 and 73/9 locomotive fleets they operate as they do not have large capacitors mounted in underframe cases.

92. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, GB Railfreight has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation.

93. In its response on 3 July 2018 GB Railfreight stated:

We do not operate any EMU's under own power as far as I am aware and the electric locos we have used , class 92 has enclosed electronics and class 73/9 has undergone a suitable check and is inspected every exam. We have no such underframe mounted equipment.

Docklands Light Railway

94. DLR have reviewed the recommendation and concluded that their existing arrangements are appropriate as they use 5 parallel capacitors rather than a single large one.

95. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, DLR has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation.

96. In its response on 29 June 2018 Docklands Light Railway stated:

Investigations are still underway into determining the root cause of the premature deterioration of the B2007 DC link capacitors. Upon conclusion of investigations and

subsequent establishment of the root cause, DLRL and KAD will jointly implement all the required actions.

Bombardier advised that in order to maintain an ALARP (As Low As Reasonably Practicable) risk on the B2007 fleet, the affected capacitors must be replaced within the next 12 months. To date, 40% of the fleet have undergone capacitor replacement; the plan is for the remainder of the fleet to have been completed by the end of June 2019.

It is also worth noting that unlike the class 455s (the train type involved in the Guildford incident), the B2007 converter capacitance is made up of 5 parallel devices, therefore an individual device failure is arguably less severe than one larger device failing.

DLRL is therefore satisfied that the current safeguards in place on the fleet are adequate, and the risk of an explosion capable of causing harm in the event of a capacitor failure is ALARP.

Nexus

97. Nexus have reviewed the recommendation and concluded that their existing arrangements are appropriate as they only use small capacitors. Nexus will be replacing their vehicle fleet in the medium term and have asked the manufacturer of the new fleet to take the report and recommendation into consideration.

98. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Nexus has:

- taken the recommendation into consideration; and
- concluded it is not applicable to them

Status: Non-Implementation.

99. In its response on 11 June 2018 Nexus stated:

Nexus owns a fleet of 90 Metro cars that operate on the Tyne and Wear Metro in Newcastle upon Tyne; the vehicles are approximately 40 years old.

The vehicles operate on a 1500 VDC overhead line system. The supply is transferred to the vehicle via a roof-mounted pantograph.

The vehicles' traction system consists of two DC traction motors that drive four axle-mounted gearboxes.

The power control and auxiliary control systems have a small number of capacitors within their electronic circuit board and control contactor circuits.

The Metro cars are due to be replaced in approximately 3 to 4 years.

No known capacitor failures have taken place on Metro cars to date.

Nexus also owns three battery locomotives for infrastructure maintenance activities (non-passenger operating vehicles). These vehicles are approximately 26 years old.

The battery loco's are very low distance usage vehicles compared to the Metro cars, which average around 12,500 Km per month.

Capacitors currently fitted to the Metro cars:

The Metro cars are currently fitted with the following capacitors:

- **C1, C2, C3 & C4 – Auxiliary Rectifier Surge Suppression Capacitor** – fitted to the auxiliary supply protection circuit and located in an under-vehicle cabinet.
- **SC – Smoothing Capacitor** – fitted to the auxiliary supply output circuit and located in a under-vehicle cabinet.
- **SK1, SK2, SK3 & SK4 – Field Injection Transformer Capacitor** – fitted to the traction power circuit and located in an under-vehicle cabinet.
- **LA – Lightning Arrester** – fitted to the power circuit between pantograph and line breaker contacts to protect the vehicle against damage from lightning strikes – fitted to the roof of the vehicle.

It is believed that many of the capacitors fitted to the Metro car fleet are the originals – around 40 years old. For example, car 4075 is fitted with these capacitors which are of small value μF (6 micro Farad) and are displaying August 1978 as the date of manufacture (original component). The capacitors referenced in the RAIB report are rated at 11mF.

Capacitors currently fitted to the Battery Locomotives:

The battery locomotives are currently fitted with the following capacitors:

- **LA – Lightning Arrester** – fitted to the power circuit between pantograph and line breaker contacts to protect the vehicle against damage from lightning strikes – fitted to the roof of the vehicle, with good ventilation.

Capacitors removed from vehicles:

No recorded evidence exists of capacitors being removed from the Metro car fleet to date.

The three battery locomotives were originally fitted with power control capacitors that were replaced in 2002 by chopper control electronic units, due to the unreliability and failure rate of the original equipment.

Existing locations of capacitors:

*All capacitors are located in two locations on the Metro car, both cabinets are under slung on the underframe and are **ventilated**. Access is via a large cover, which is secured by locking handles, and a Castell key system. Access is also available via a bolted rear panel.*

All capacitors are small, and are low rated, hence do not get very hot during normal operations and are very reliable. Very few capacitor replacements are recorded in the history of the Metro cars.

Actions taken by Nexus:

1) Continue with the existing maintenance regime of visual inspection of under slung cabinet equipment contents and condition, every 5 months or 62,500 Km on the Metro cars, and every C exam – 6 months on battery locomotives. As per the respective maintenance plan for the vehicle types.

2) The recommendations of the RAIB report were passed on to the Metro futures department of Nexus (February 2018) for consideration with our contracted consultants, during the procurement process for the replacement fleet of new trains.

3) A review of the existing traction circuit and componentry location has taken place and no changes are planned for the class 599 Metro car, due to age, capacitor history and pending replacement new fleet.

Strathclyde Passenger Transport Executive

We will ask them to confirm what response they have had from Stadler with regards to new stock and what action they are taking as a result.

100. SPTE have reviewed the recommendation and concluded that their existing arrangements are appropriate for their current fleet. SPTE will be replacing their vehicle fleet in the medium term and have asked the manufacturer of the new fleet to take the report and recommendation into consideration and will report back to ORR any actions identified.

101. After reviewing the information provided ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, SPTE has:

- taken the recommendation into consideration; and
- is taking action to implement it, but has not yet provided ORR with full details of actions being taken in response to the recommendation.

Status: Progressing. ORR will advise RAIB when further information is available regarding actions being taken to address this recommendation.

102. In its response on 29 June 2018 Strathclyde Passenger Transport Executive stated:

Current rolling stock

No risk identified.

This incident was caused by a build-up of explosive gases from a defective capacitor in a sealed traction compartment. The current fleet does have capacitors in the Main equipment case which does have a seal around the case covers and the train. We are not at risk because there are vent holes around the base (the mating face between the covers and the train) of the MEC covers which would allow any gas produced by a defective capacitor to escape.

New Stock

SPT have provided the report to Stadler (manufacturer of new rolling stock assets) who are now fully aware of the recommendations and response required. Stadler traction engineers are working with their traction suppliers (ABB) to review the design and respond on the mitigation required.