PASSENGER CONTAINMENT

A review of research carried out by RSSB on behalf of the rail industry and core recommendations

Published by: Rail Safety and Standards Board (RSSB) Limited
Evergreen House
160 Euston Road
London
NW1 2DX

31 July 2007
# CONTENTS

<table>
<thead>
<tr>
<th>SECTION</th>
<th>SUBJECT</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Executive Summary</td>
<td>ii</td>
</tr>
<tr>
<td>1</td>
<td>General introduction and background</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Investigating injuries and their causes</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Reviewing accidents and their consequences</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>Seeking solutions</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>Investigating seat belts</td>
<td>26</td>
</tr>
<tr>
<td>6</td>
<td>Seat belts and loss of survival space</td>
<td>36</td>
</tr>
<tr>
<td>7</td>
<td>Performance of windows</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>A summary review of containment</td>
<td>54</td>
</tr>
<tr>
<td>9</td>
<td>Escape and rescue</td>
<td>58</td>
</tr>
<tr>
<td>10</td>
<td>A strategy of containment</td>
<td>74</td>
</tr>
<tr>
<td>11</td>
<td>A summary review of windows as a means of escape</td>
<td>78</td>
</tr>
<tr>
<td>12</td>
<td>Risk assessment summary</td>
<td>82</td>
</tr>
<tr>
<td>13</td>
<td>In conclusion</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Appendices A to M</td>
<td>102</td>
</tr>
</tbody>
</table>

© Copyright 2007 Rail Safety and Standards Board

This publication may be reproduced free of charge for research, for private study or for internal circulation within an organisation but not for any other purpose. This is subject to it being reproduced and referenced accurately and not being used in a misleading context. The material must be acknowledged as the copyright of Rail Safety and Standards Board Ltd (which is a company limited by guarantee) and the title of the publication specified accordingly. For any other use of the material please apply to the Head of Research and Development for permission. Any additional queries can be directed to enquiries@rssb.co.uk or telephone +44 (0)20 7904 7518.

This publication can be accessed via the Rail Safety and Standards Board website, www.rssb.co.uk.
EXECUTIVE SUMMARY

The Rail Safety and Standards Board (RSSB) has over recent years conducted research into crashworthiness of rail vehicles on behalf of the rail industry with the objective of improving rail accident prevention and the protection of passengers. The research described in this report was initiated to identify the causes of injuries to passengers, to understand the way in which those injuries were sustained and to identify possible ways of reducing or eliminating such injuries.

Accident data analysis indicated that, while the overall level of injuries to passengers has been declining, improving designs of rail vehicles has led to a change in injury patterns, with involuntary exit becoming a more significant cause of injury. During the early stages of the research, an accident occurred at Ufton Nervet, in which a High Speed Train (HST) hit a road vehicle on a level crossing. During the subsequent derailment of the train a number of passengers were thrown out of the train and received fatal injuries. In the aftermath of this type of fatality there were calls from members of the public, some affected parties and MPs, for the fitting of seat belts.

This report summarises the research conducted into the most effective way of reducing or eliminating involuntary exit casualties. The focus of the research was quite deliberately restricted to identifying the most effective solutions to reduce or eliminate such injuries. Equally deliberately all commercial considerations of affordability or the implications for carrying capacity were excluded from the work.

Recognising the need to demonstrate the integrity, credibility and thoroughness of the work, experts were engaged with appropriate experience in air, marine, rail and road transport. Experts with particular experience in protection and evacuation across these transport systems were also engaged. The fire and rescue services and paramedic organisations were consulted.

An extensive amount of information was gathered from hundreds of passenger witness statements, detailed interviews with survivors regarding their experiences and actions, press reports and press interviews. The movements of the vehicles during the accidents, their final dispositions and the interior damage, including signs of injury, were identified and recorded. In addition to the actual accidents investigated in detail, nearly 100 accident scenarios were also identified and included within the evaluation.

Involuntary exit was found to occur principally where vehicles had jack-knifed and / or overturned and, in most cases, the involuntary exit was via a window. Two possible alternative solutions were therefore apparent, namely restraining passengers to their seats or providing stronger windows.

Consideration of protective devices fitted to the different forms of transport highlighted that the risks being mitigated by the protective devices differed very considerably, illustrating that the use of a particular protective device in
one form of transport did not automatically render it applicable or suited to other forms of transport.

Anthropomorphic Test Devices (ATDs or crash test dummies) were found to have been developed specifically to test particular protective devices. The commonly used Hybrid 3 ATD was suitably instrumented for assessing chest loads resulting from the use of lap-and-diagonal (three-point) seat belts, but was not particularly suited to assessing impacts against rail vehicle tables. These limitations also impaired its ability to effectively assess the use of two-point seat belts (lap belts). A variant of the Hybrid 3 dummy was therefore specifically developed to facilitate the valid assessment of the effect of tables and of two-point seat belt installations in rail applications.

Two-point and three-point seat belts were evaluated in an extensive programme, using ATDs representative of small, medium and large sized people and a variety of seat intervals representative of those in current vehicles. The results of the tests revealed that two-point seat belts were likely to increase the severity of injuries, particularly to the neck, to unacceptable levels, whereas the injury levels experienced by unrestrained passengers occupying seats designed to the latest crashworthy standards were well within acceptable limits. With three-point seat belts it was found that the injury levels were reduced below those for unrestrained passengers occupying crashworthy seats – although both were within acceptable limits. However, in order to support the increased loadings imposed by the use of three-point seat belts, the seats had to be strengthened, negating their in-built crashworthiness and consequently increasing the neck injury levels to unrestrained passengers to unacceptable levels.

Investigation of recent major accidents also revealed that in areas of the vehicles where survival space had been severely reduced or lost due to collapse or crush of the vehicle structure, passengers had been uninjured. It was evident that they had been thrown clear in the impact before potentially fatal injuries could have been inflicted. Analysis showed that for every passenger whose life may have been saved by seat belts preventing involuntary exit, potentially eight passengers’ lives may have been lost by being restrained in areas where loss of survival space occurred.

Seat belts are predominantly designed to protect people in the event of a longitudinal impact. It was evident that the effectiveness of seat belts in the event of jack-knifing and roll-over could not be relied upon.

The use of stronger windows was investigated as an alternative means of preventing involuntary exit of passengers. Historically, breakable windows had been provided as an optional escape route in the event of an accident and to facilitate rescue of passengers by the fire and rescue services. However, the presence of such breakable windows had resulted in most of the cases of fatality due to involuntary exit during the course of accidents. The provision of windows with better containment characteristics directly addresses the jack-knifing and roll-over cases.
Investigation of past accidents had also demonstrated a need to protect against penetration of objects through the windows during a derailment, as well as the need to prevent passengers being thrown or falling through windows. Whilst seat belts could not protect against such penetration, windows could be designed to minimise the risk.

A suite of tests was developed which simulated external impact from solid derailment debris, followed by full impact from a passenger falling across the full width of the vehicle as it rolled over, followed by a passenger standing on the glass as part of an escape manoeuvre. A laminated glass window was successfully developed to withstand this succession of tests simulating a realistic accident scenario. The window developed was of a thickness that opened up the possibility of retrospective fitting to existing vehicles where deemed appropriate. The toughened glass type of window fitted generally to pre-1994-built vehicles, and fitted as the escape window in more recent vehicles, was subjected to the suite of tests and the absence of any significant level of containment was clearly demonstrated.

Consideration was given to the possibility of the new type of glass impeding escape. Tests in a rolled-over rail vehicle emphasised that exit via windows, with the need to climb up armrests and break a window above the head, was a very difficult and hazardous activity. Escape through the window of an upright vehicle, confirmed by recent accidents, was also found to be a dangerous activity in itself. Specific scenarios were reviewed with regard to the effect of installing laminated glass for containment throughout rail vehicles, including cases of fire, explosion, derailment into water and vehicles stranded without power on a hot day. The mitigating provisions were considered to reduce the risk of entrapment by laminated glass to several orders of magnitude below the risk of involuntary exit resulting from the continued use of toughened glass. Accident situations world-wide were reviewed to ensure that all realistic scenarios had been taken into account.

The reasons passengers gave for selecting their routes of exit in British cases were considered in the light of each individual circumstance. No case was found where a life would have been lost if a window had not been available for escape. Emergency lighting requirements have been developed as one means of encouraging passengers to delay their exit until safe to do so.

The newly developed window, having met the new containment test suite, was subjected to access trials by the fire and rescue services. Their ability to enter through the new type of window, with tools currently carried on rescue vehicles, was undiminished. Access times of less than 2 minutes were achieved, and the fire and rescue services considered this to be insignificant when compared with the time to arrive on site, and passenger survival time. The fire and rescue services fully endorsed containment as being the priority and emphasised that entry through windows was not their preferred route for rescue, although it can be used for stretcher cases.

Implementation by train operators of a common strategy, to avoid confusion over whether windows were provided on trains for escape or not, would
require the planned and progressive removal of all instructions referring to escape via windows and the removal of glass-breaking hammers for windows. The installation of laminated glass could then be carried out on an ad hoc basis, with the replacement of toughened glass by laminated glass whenever windows required replacing, or on a fleet-by-fleet basis as appropriate (possibly during refurbishment).

The proposed strategy was subjected to risk assessment, both qualitative and quantitative. This identified that the immediate removal of hammers would cause a very modest increase in risk (relating to those very rare events where breaking a window would be beneficial to passengers). However the assessment concluded that the benefits of enabling operators to proceed with ad hoc and planned replacement of windows significantly exceeds this small increase, and therefore that this approach should be adopted.

**Overall Conclusion and Recommendation**

The conclusion reached, taking account of the extensive research and risk assessment is that breakable windows should cease to be a recognised method of escape to passengers and that laminated glass should be progressively fitted throughout rail vehicles.

In support of this:

a) RSSB should initiate changes to the relevant Railway Group Standards – through the normal consultation process involving the industry and public consultation, and

b) A consistent strategy should be adopted by train operators to have a consistent message for passengers in the event of any future rail accident.

The core message to passengers should be along the following lines:

1. **Travelling by rail is one of the safest forms of travel.**

2. **You are very unlikely to be involved in an accident, however, if you are, it is usually safest to stay on the train (because other trains could still be running on adjacent lines and power supplies may not yet have been switched off).**

3. **In the event of an accident:**

   **First priority:** You should remain where you are on the train and await rescue by the emergency services.

   **Second priority:** If it is not possible to do this because of a threat, then you should move to a position of safety further along the train and await rescue by the emergency services.
**Third priority:** If it is not possible to do this, you should evacuate the train via the external bodyside doors, or an open vehicle (gangway) end.

You should not attempt to exit trains through windows.

This document is structured as follows:

**Section 1** provides a general introduction to the research and the background against which the work was carried out.

**Section 2** describes the extensive investigation into the injuries sustained in rail accidents, their severities and causes, describing the changing pattern of injuries with time. It identifies involuntary exit, where passengers fall or are thrown out of the vehicle during an accident, as an emerging cause of injury in more modern rail vehicles.

**Section 3** describes a review of actual and possible accident scenarios in order to provide an understanding of the types of accidents that can happen, what happens to vehicles during the course of such accidents and the final condition of vehicles after the accident.

**Section 4** describes the process of seeking solutions to the problem of involuntary exit, the two most obvious potential solutions being the installation of seat belts to keep passengers in their seats or the installation of stronger glass to prevent passengers being thrown or falling out. The question of transferability of solutions from one form of transport to another is considered and the investigation into methods of assessing the likely reduction in injuries is described.

**Section 5** describes the testing of seat belts of the type used in aircraft and in cars. It also reviews the evaluation of likely injury severities.

**Section 6** describes the investigation of an unexpected phenomenon that was discovered in analysing a number of serious accidents in which passengers escaped areas of major vehicle damage without significant injury – in many cases, without any injury at all.

**Section 7** describes the development of a window to give improved retention of passengers in the event of an accident. It describes the development of a suite of tests that simulated a rail accident in order to provide a realistic assessment of the likely performance.
Section 8 provides a summary review of the containment issues described in the previous sections.

Section 9 reviews the potential effect of using stronger windows for improved passenger containment on the ability of passengers to escape after an accident or the effect on the ability to rescue passengers.

Section 10 considers the development of a strategy of containment based on the findings of the research.

Section 11 provides a summary review of the issues arising from the use of windows as a means of escape.

Section 12 provides a summary of the risk assessment undertaken qualitatively and quantitatively to assess the benefits or disbenefits of changing to a strategy of all-laminated glass.

Section 13 brings together the conclusions emerging from all RSSB work on containment, including the body of research and the risk assessment.
SECTION 1

GENERAL INTRODUCTION AND BACKGROUND
1.1 INTRODUCTION

The Rail Safety and Standards Board (RSSB) has, over recent years, been conducting research to support the industry in rail accident prevention and improved protection of passengers in the event of accidents occurring. This area of research has covered a wide range of issues relating to safety of passengers. The high level approach to managing the risk can be described by the following sequence:

1. Prevent the accident from happening
2. Where this is not possible, design the train to absorb the energy of collision and protect passengers from the impact.
3. Where the passenger cannot be totally protected from the impact, design the vehicle interiors to prevent injury.
4. Where it is impossible to prevent injury, design the vehicles to prevent incapacitation injury that would prevent escape.
5. Where it is impossible to prevent incapacitating injury, ensure that rescue is adequately facilitated.

This paper concentrates on work carried out by RSSB in support of points 2 to 5. RSSB’s contribution to the prevention of accidents is very extensive and is reported elsewhere.

The rail industry has undertaken a considerable amount of work since the Clapham accident of 1988 to develop vehicle designs that will absorb collision energy. There is of course a practical limit to the amount of such energy that can be absorbed. RSSB has conducted research into the possible improvement of obstacle deflectors designed to clear large objects, such as cars and cows, from the path of the train. It has investigated possible improvements into lifeguards designed to remove smaller objects, such as concrete sleepers or lengths of rail placed on the track by vandals, from the interface between the train wheels and the rail. The factors influencing the ability of a train to remain upright and in-line in the event of a collision are currently being further investigated.

In the event of an accident in which the train hits or is hit by another object (“primary impact”), passengers within the train may rapidly come into contact with the seat in front of them or other interior features. The impact of the passenger with interior features is referred to as “secondary impact”. Work has been undertaken to improve vehicle interior designs to protect passengers from injury caused by secondary impact. It is important to appreciate, however, that any protective device may itself be a cause of injury sustained as a result of the method of protection, but without that protection the injury sustained could be very significantly greater. Thus, for example, passengers being protected from serious injury may, by the nature of those protective systems, sustain minor injuries. The presence of significant numbers of such minor injuries in the statistics should not therefore be taken as a clear indication that there is a problem that requires addressing.
The significance of the statistics needs to be understood in order to ensure an appropriate interpretation of the data.

It was recognised that, whilst minor injuries are significantly more numerous in most accidents, the priority must be the prevention of fatalities or of major injuries that may cause permanent incapacity.

This report seeks to summarise the work carried out and to give an overview of the associated projects.

1.2 BACKGROUND

Research projects were initiated by RSSB to identify the causes of injuries to passengers, to gain an understanding of the way in which those injuries were sustained, and to identify possible ways to reduce or eliminate such injuries. During the course of this research, an accident happened at Ufton Nervet in which a train hit a road vehicle on a level crossing and, during the subsequent derailment of the train, a number of passengers received fatal injuries. The accident provided an opportunity for investigation into the causes of passenger injuries on a scale not considered to be feasible previously.

In the accident at Ufton Nervet a number of passengers were thrown out of the train and received fatal injuries at some stage during the accident. In the aftermath of this type of fatality, there were calls from members of the public, some affected parties, and MPs, for the fitting of seat belts. The research programme was already conducting an investigation of the topic of passenger restraints, including seat belts and air bags, and this was given a higher priority in the programme in order to assist an informed decision being made regarding the most effective way forward.

At the outset of the research it was determined that the investigation should focus on the nature of injuries sustained, the cause of those injuries, the mechanism by which the injuries were sustained and the most appropriate solutions to reduce or eliminate such injuries. No consideration was to be given to issues such as affordability or the implications for carrying capacity – commercial issues being excluded from this aspect of the investigation. It was recognised also that the integrity and thoroughness of the research must be clear in order for the work and its conclusions to be credible.

It was considered essential that the experience and developments within other transport industries should be taken into account and a conscious decision was taken to include, within the project, parties that had such experience. The research was undertaken by DeltaRail, formerly AEA Technology Rail (AEAT), personnel having considerable experience of investigating injuries in rail accidents over many years. TRL (formerly the UK’s Transport Research Laboratories) was engaged in support of DeltaRail, their personnel having considerable experience in the development of crash test dummies, crash simulation, application of seat belts in road vehicles and the interaction between passengers of all ages and restraint devices. Cranfield University also supported the research with personnel experienced
in the aviation field, emergency evacuation, human factors and psychology, and the debriefing of persons involved in accident situations. (See also Appendix A.)

As indicated above, statistics can provide very valuable information in such research, but it was also recognised that it was vital to understand the stories behind the statistics. To this end it was considered essential that the experiences of passengers should be sought out in order to facilitate a correct interpretation of the statistics. The assistance of British Transport Police (BTP) was therefore requested in order to obtain information from passengers involved in the Ufton Nervet accident and also to seek agreement of passengers to be interviewed specifically for the research.
SECTION 2

INVESTIGATING INJURIES AND THEIR CAUSES
2.1 UNDERSTANDING INJURIES AND THEIR CAUSES

It was considered essential to obtain first-hand information regarding the experiences of passengers for the research to be definitive and contact was made with the British Transport Police (BTP) to seek their co-operation to that end. Confidentiality of information was assured and BTP provided de-personalised witness statements in order to provide maximum information whilst preserving anonymity. The passenger information included the nature and severity of the injuries sustained and the cause of those injuries. For the Ufton Nervet accident almost two hundred witness statements were provided from which a wealth of information was obtained. A rigorous process was then used to identify the location of each passenger within the respective vehicles. A comprehensive level of information was established (see Appendix B), including:

- **Personal details**
  - Gender
  - Age (where available)
  - Whether Passenger or Crew

- **Vehicle details**
  - Vehicle identification
  - Type of vehicle (definitive of layout)
  - Seat number in which passenger located
  - Whether in-line seating, bay seating or table bay seating
  - Whether seated adjacent to the aisle or adjacent to the window
  - Whether facing or back to direction of travel

- **Injury details**
  - Body region injured (head, neck, abdomen, back, arm, leg etc)
  - Type of injury (cut, bruise, break, concussion, fatality etc)
  - Injury severity (assessed using the internationally recognised Abbreviated Injury Scale, or AIS)
  - Causation (the vehicle interior component related to the injury)

- **Treatment location**
  - Hospital
  - On site

- **Egress method**
  - Door
  - Window
  - Inter-vehicle (gangway) connection
  - Hole in vehicle shell

In order to establish a more complete picture it was necessary to establish the condition of the vehicles in each passenger location and the time-history of each vehicle during the course of the accident. Every vehicle involved in the accident was surveyed and video walk-through records were taken in order to permit the research team to ‘walk through’ the vehicles repeatedly during the investigation looking for further corroborating information. To supplement the video records, over four hundred photographs were taken to record each area of vehicle damage and any local indications of impact or injury that were present. The photographs were linked to specific locations of the vehicles,
confirmed by the video records, and the passenger statements. Thus a record was developed linking passenger injuries with damage at the positions in the vehicle where those passengers were located. A comprehensive level of evidence was collected and recorded (see Appendix C), including:

- Every detail of interior damage
- The threats to people at every seat location
- Every location at which a hammer had been removed
- Every window broken, indicating whether by hammer or by impact
- Every light-stick used
- The exit route of nearly every passenger
- Every emergency door release operated
- Every impediment to exit

Using the above information it was then possible to relate passenger injuries with the descriptions of how they were injured and the vehicle evidence (both the damage and signs of injury) in order to determine the injury mechanisms. From such an analysis it was possible to identify interior features with particular types of injury and the severity of such injuries (see Appendix D).

Following the above analysis, including a review of how much information they had provided in their witness statements, a number of passengers from each of the vehicles were selected as being able to provide an account of events within their vehicles. 24 passengers were selected who, because of the anonymity, were approached by the BTP and asked whether they were prepared to assist the research. All were willing and an additional passenger later volunteered – twenty five passengers in total. The interviews were undertaken by appropriately skilled personnel from Cranfield University, following approval of a validated ethics code defining the approach of the interview, with trauma counsellors available. No counselling was needed.

### 2.2 EXTENDING THE INVESTIGATION

The investigation of the Ufton Nervet accident demonstrated how, with the appropriate level of information, it was possible to mentally re-run an accident and create an informative time-history of the experiences of many passengers during the accident. Passenger descriptions of what happened to them and what they did were matched with the evidence from the vehicle itself and this helped to give an understanding of the contribution of the vehicle interior features to the injuries sustained (see Appendix E).

It was recognised that analysing a single accident could distort the conclusions as a result of the particular circumstances of that accident. This type of analysis was therefore extended to six additional, significant accidents. The accidents at Watford, Southall, Ladbroke Grove, Hatfield, Great Heck and Potters Bar were selected. Despite the passage of time, extensive records were able to be compiled by combining information from a number of sources. With the further co-operation of BTP, more than 600 additional passenger witness statements were obtained and analysed, from which it was possible to identify the majority of injuries sustained. The motions of each vehicle involved in each of the accidents were identified and the damage sustained
by each vehicle was determined (see Appendix F). Again, from the data available, it was possible to identify the cause of the majority of injuries sustained. A preliminary consideration of possible protective measures revealed, not surprisingly, that there was no solution that could resolve all issues. The solution to one problem could create others.

From the seven accidents the cause of fatalities, major injuries and minor injuries were analysed and a significant extract from that information is given in the table below.

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of Fatalities</th>
<th>No. of Involuntary Exits</th>
<th>No. of Fatal Involuntary Exits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watford</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Southall</td>
<td>7</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Ladbroke Grove</td>
<td>29</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hatfield</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Great Heck</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Potters Bar</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Ufton Nervet</td>
<td>5</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>60</strong></td>
<td><strong>20</strong></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>

Table 1 A key extract of injury data

One category of injuries is described as “involuntary exit” which covers people exiting the vehicle during the accident in a variety of different ways which were significant to the solutions. It can be seen that, of the total number of fatalities occurring in the seven accidents, 20% were related to involuntary exits from the vehicle. Also of significance is the fact that, of all people falling out of the vehicle windows, over 50% were fatalities. One person was killed by debris entering the window prior to exiting the vehicle. Analysis of the evidence collected indicated that involuntary exit occurred in an accident when a vehicle was subjected to two events during the accident; namely, when vehicles separated and also overturned. Under such accident conditions,
people’s exit routes varied. People fell out of the vehicle either through a window, or through the vehicle end-connection (gangway) or through ruptures in the vehicle body shell, as illustrated at Potters Bar and at Ufton Nervet (Figure 1).

### 2.3 A CHANGING PATTERN OF INJURIES

In common with all forms of transport, the railways are continually changing. It was vital, therefore, to consider whether the types and causes of injuries were changing too. It was pointless seeking to address a particular injury mechanism if that mechanism was specific to types of train no longer in use.

Investigation of accident statistics and casualty data over a period of approximately 30 years confirmed that significant changes had taken place.

![Accident Casualty Data, 1973-1983](image)

**Figure 2 Accident Casualty Data, 1973-1983**

The most significant cause of injury during the period of 1973 to 1983 was occupants being crushed as the vehicle body collapsed. This was characteristic of many accidents involving the Mark I type of construction, in which the chassis of the vehicle was designed to carry the service loads whilst the body shell was not designed to carry major structural loads. The collision at Clapham illustrated the typical consequence of collision involving such rail vehicles. Cases of involuntary exit via windows were seldom experienced as people were killed as the vehicles themselves were crushed. See Figure 3.
At the beginning of this period the design of rail vehicles was already changing significantly, the body shell becoming integrated with the chassis and becoming a part of the load-bearing structure of the vehicle. Such vehicles were designated the Mark II design, which was subsequently superseded by a further enhancement in the structural strength of the body shell in the Mark III design. Figure 4 indicates the changed profile of injury mechanisms.

![Figure 3 Clapham Accident](image_url)

**Figure 3 Clapham Accident**

It is evident from Figure 4 that, with the increasing structural integrity of the vehicles, involuntary exit became a more significant cause of injury during the later period. Crush injuries diminished significantly with the decline of Mark I vehicles featuring in the accidents reported. The increasing dominance of

![Figure 4 Accident Casualty Data, 1984-2004](image_url)

**Figure 4 Accident Casualty Data, 1984-2004**
vehicles with strong body shells gave better protection from crush, although windows were less strong than the metal body shell surrounding them. Whilst windows were not the only route of involuntary exit, they were nevertheless the most significant route, as illustrated by the accident at Potters Bar, Figure 5.
SECTION 3

REVIEWING ACCIDENTS AND THEIR CONSEQUENCES
3.1 ACCIDENT SCENARIOS

The objective of the research was not merely to understand what was causing injuries, but also to investigate solutions to reduce or eliminate those injuries. As indicated above, however, it is vital to consider the possibility that measures to reduce one type of injury could make another situation worse. In order to facilitate such a review, a study was made of accident scenarios.

RSSB’s earlier ‘Stay-or-Go’ research sought to identify all potential accident or incident scenarios (see Appendix G) as a basis for assessing the risk to an individual passenger remaining on the train after an accident, compared to the risk to that passenger deciding to get off. However, the work undertaken for that project considered those cases where a passenger was relatively uninjured in the accident and was located in a vehicle that was relatively undamaged or unaffected. In such a situation the passenger had a realistic choice of remaining within the vehicle or getting out. The research described here was concerned with those cases where passengers were injured and where the vehicles had been seriously affected by the accident. Nevertheless, the approach to identifying the final vehicle situations (or, “end states”) was considered to be equally applicable, even though the use of those end states in the analysis differed very significantly (see Appendix H).

Three top level events were considered as follows:
1. The train is derailed
2. The train is affected by fire
3. The train is unable to proceed.

For each of these top level events an event tree was developed by Risk Solutions Ltd., taking account of all of the variables that differentiate between one accident (or incident) and another within that type of event. A typical event tree is included for illustration in Figure 6.

![Derailment Event Tree – Ufton Nervet Identified (One Vehicle)](image)
As can be seen from that illustration, the accident scenarios arising from the derailment consideration included:

- Whether clearances were maintained relative to the infrastructure
- If not, whether it deflected towards adjacent tracks or away from them
- Whether vehicles within the train over-turned
- Whether the derailed vehicles collided with lineside structures
- Whether such impacted structures collapsed onto the train
- Whether fire occurred
- Whether a fuel source was present, even where no fire had occurred.

The derailment event tree identified 27 different end states, ie 27 different final states of vehicles following the derailment. For each state, a number of modifiers were applied, such as whether the accident happened on a line with third rail electrification (the third rail being at ground level), whether the train was heavily loaded or not, whether the train was in a tunnel or open ground, traffic density etc. Such modifiers increase the number of scenarios considered. Similarly, the fire event tree identified four basic end states that, again, were expanded by the modifiers. Finally, the ‘train stop’ event tree identified the single situation, considering that the train was not involved in an accident, but had merely lost power, heating or cooling and lighting. Modifiers applied to this situation particularly included environmental conditions. A total of nearly one hundred accident and incident scenarios were identified.

The objective in using the technique in this research was not to identify the risk to passengers staying in the vehicles or the risk to passengers getting out of the vehicles in these scenarios. The objective was to provide a framework within which to evaluate the potential consequences of any proposed injury reduction measures in each of the accident scenarios identified.

It should be stressed that the scenarios identified included potential accident scenarios, not merely those that had already occurred, and it was possible to identify all vehicles in each known accident with one of the scenarios. There was no vehicle case failing to match a scenario (See Appendices G and H).

### 3.2 DIFFERENT ACCIDENTS, THE SAME CRASH

The photograph of Ufton Nervet, repeated as Figure 7, shows that vehicles within this single event had very different experiences. A number of vehicles remained almost upright, but experienced a mainly longitudinal crash pulse. Other vehicles remained almost upright, but swung to one side. One vehicle jack-knifed across the track and rolled over.
Another vehicle slid along the track on its side and one vehicle was bent double. Therefore, although this was recorded as one train accident, it was actually ten individual vehicle accidents. The injuries experienced by the passengers in each vehicle were the result of these individual events.

Rail accidents are very rare and accident data is very limited. However, analysis of evidence from the accidents showed that passengers were injured as a result of what happened to their individual vehicle, not as a result of what happened to the train. Thus, even though the number of train accidents considered was relatively small (7), every vehicle within each train had its own accident with the vehicle in front and the vehicle behind it (52 vehicles). Each passenger within each vehicle had his or her own accident with the interior of the vehicle in which each was travelling. Since the objective of the research was to reduce or eliminate injuries, this was the crucial data. Instead of seven accidents, or even instead of 52 passenger vehicles in those seven accidents, there were around 1000 individual passenger accidents within the vehicles which resulted in injuries of varying severity – this was a large amount of data and it was statistically significant. Comparing the accidents, it became evident that individual vehicles within several very different accidents experienced very similar events (See Figures 8 to 11).

Whilst, therefore, it may be appropriate to consider the accident involving the complete train as a single event for the purpose of comparing types of accident, for the purpose of investigating the protection of passengers against
injury it is essential to consider each individual vehicle separately. It is vital to compare injuries between vehicles experiencing similar events.
SECTION 4

SEEKING SOLUTIONS
4.1 REDUCING THE PROBLEM OF INVOLUNTARY EXIT

As indicated above, passengers had involuntarily exited the vehicle in which they were travelling, during the course of the accident, as a direct consequence of the dynamics of the vehicle. The mechanisms of such unfortunate occurrences varied. In some cases windows had broken as the vehicle rolled on its side, with passengers on the high side of the vehicle falling across the vehicle and through the opening created. Passengers on the low side of such a rolled vehicle, next to the broken window, had been dragged through the window as a result of limbs contacting the passing ground. In other cases passengers had fallen through the emerging gap between vehicles as they parted during the aftermath of the initial collision. In other cases, such as at Potters Bar, the window was initially broken by airborne debris from the collision, allowing passengers to be projected through the broken window during the jack-knifing and rolling of the vehicle. Thus, although for simplicity all of these occurrences are referred to by the single description of involuntary exit, the different causes of the involuntary exits had to be considered separately in evaluating the effectiveness of proposals to eliminate them.

There were two potential approaches to reducing involuntary exit, namely keeping people in their seats (e.g., seat belts) and fitting stronger windows. The former sought to keep passengers away from potentially breakable windows whereas the latter sought to prevent the windows from breaking.

4.2 TRANSFER OF SOLUTIONS BETWEEN MODES OF TRANSPORT

Measures to prevent injury are found in other forms of transport such as road and air. It would be natural therefore to suppose that any solution used in one form of transport might be suitable for all forms of transport. The research therefore included a review of such protective measures and an investigation into the applicability of those measures in the case of rail vehicles.

Any protective measure is introduced to mitigate a particular risk and it is the risks being mitigated, and the circumstances in which those risks arise, that must be compared across industries. Of equal importance is the consideration in each case of the consequences of not mitigating the risk, or of seeking to mitigate it by other means.

The particular periods during which passengers are perceived to be at greatest risk in an aircraft are during take-off, air turbulence and landing. During each of these occurrences passengers are required to be seated and wear seat belts. The brace position is to be used in an emergency. The risk during air turbulence, for example, is that the aircraft will suddenly drop significantly faster than under gravitational acceleration – therefore faster than an unrestrained passenger – causing serious head injuries as the passenger’s head is struck by the rigid cabin ceiling. In such circumstances a two-point (or lap) belt is sufficient to keep the passenger with the rapidly descending seat and the head injuries are prevented. Such a risk is not analogous to road
transport or trains and illustrates the need to fully evaluate the risks being mitigated and the appropriateness of the method considered for mitigation.

4.3 ASSESSMENT OF LIKELY INJURIES

Since the objective is the protection of passengers against injury, proposed solutions must be assessed in relation to the injuries that are likely to be sustained with and without the device. In the aircraft case referred to above, the key requirement is to ensure that the seat belt and supporting seat structure are strong enough to keep the passenger ‘attached’ to the seat, particularly in the case of air pockets. The measurement of injury levels would be deemed academic since fatality may be the expected consequence of not being restrained. The seat belt and anchorage strength would therefore be the key criteria and the injuries inflicted would not be critical.

In other forms of transport the assessment of the severity of consequential injuries, with and without protection, is more appropriate. To do this it is necessary to be able to assess injury levels in both cases. Historically, injuries have been assessed by the use of Anthropomorphic Test Devices (ATDs), commonly referred to as crash test dummies. It is important to recognise that ATDs are designed to test a particular feature and not to fully replicate the human body. ATDs must be designed to measure the appropriate parameters in relation to a particular injury mechanism.

In the early days of car safety investigations, one of the most serious injury mechanisms was the impaling of drivers on the steering columns of their cars as a result of a head-on collision. To militate against this commonly fatal injury mechanism, the three-point (lap and diagonal) seat belt was introduced for drivers. Here any injuries that may have resulted from the seat belt loads imposed on the chest were preferable to being impaled on the steering column. In time this safety device was introduced for front seat passengers since it was recognised that, in a head-on impact, a front seat passenger was likely to be catapulted through the windscreen and into the impact (or crash) zone itself with a very high risk of fatal injuries being sustained. Again, chest injuries caused by the seat belt were considered to be preferable to being catapulted into the impact zone. Ultimately, the fitting of seat belts to rear seats (either two-point or three-point) was introduced primarily to prevent fatalities arising from rear seat passengers being catapulted into the back of front seat occupants, inflicting fatal injuries on the front seat occupants particularly to the head and neck region. In each of these cases, within the relatively close confines of a car, the potential consequences of wearing such belts was deemed to be preferable to the injuries that could have been sustained otherwise. The gradual introduction of air bags in the various seat positions reflected the growing recognition that, in severe impacts, the injuries caused by the seat belts themselves were unacceptable, even though less than those injuries incurred without the belts. A lower severity is only of benefit if it is survivable. The development of ATDs was particularly focused on the effects of seat belts on the chest and the devices were designed to measure chest loads in the equivalent of a head-on impact. The Hybrid 3 ATD was developed to permit this type of assessment.
Such ATDs did not require significant rotation of the hip and flexibility of the lower spine since these were not relevant to the accident case replicated. For research into the use of two-point seat belts, using ATDs with restricted mobility of the hip and lower spine was considered to be inappropriate for the pursuit of reliable results. Additionally, a key potential injury was considered to be loads to the abdominal region, which could not be measured appropriately by the standard ATDs available. Research into the crashworthiness of rail vehicles had already identified a problem of injury assessment in relation to tables impacting the abdominal region. Accordingly an ATD was developed under this research, based on the standard Hybrid 3 ATD, which permitted rotation of the lower spine and hip region. The ATD also incorporated an instrumented abdomen. Instrumentation in the chest was improved to permit more accurate measurement of the effects of impacts in the abdominal region. This ATD developed specifically for rail was designated the Hybrid 3RS (see Figure 12).

Figure 12 Hybrid 3RS

It was recognised that the enhanced characteristics of the Hybrid 3RS ATD made it ideal for the testing of two-point seat belts and also for unrestrained occupants. In the confines of a rail vehicle, with seat rows in-line, sometimes referred to as airline style, an occupant thrown forward in an impact will move forward in a seated posture until the knees hit the seat in front. At this point, further forward movement of the hip is stopped by the knee contact. The chest and head then rotate about the hip in an inverted pendulum motion. This movement is not fully replicated by the standard ATDs. The unique design of the Hybrid 3RS was considered to provide, for the first time, a tool able to appropriately measure the injury potential of two-point seat belts and unbelted occupants in confined seating for all forms of transport.

The earlier research into the performance of tables, referred to above, identified the limitations of existing ATDs for assessing abdominal injuries or the effect of types of impact where significant rotation of the hip and lower spine would occur. Further research into table performance was therefore placed in abeyance whilst a suitable ATD was developed – the Hybrid 3RS. With the advent of the Ufton Nervet accident, and with the decrease in the numbers of tables fitted in modern rail vehicles, a greater priority was given to the problem of involuntary exit. It was recognised that realistic representation of flexibility in the lower spine and hip was essential for valid assessment of two-point seat belts, and the research therefore benefited from the availability of the Hybrid 3RS ATD developed during the earlier research. Further work regarding tables is the subject of on-going research in collaboration with the United States.
The programme of research undertaken by RSSB was originally intended to explore how future vehicles could be designed to reduce the vulnerability of passengers to injury in the event of an accident, learning lessons from past accidents. It was recognised that, whilst some solutions may be applicable retrospectively to existing vehicles, the main benefit was likely to be gained by influencing the design of new vehicles. With the reduction in the provision of open-bay seating and table bays in most types of modern rail vehicle, the greater initial emphasis in the research has been placed on vehicles having in-line (sometimes referred to as airline style) seating. The question of open bays is nevertheless being investigated as part of a more in-depth consideration of injury mechanisms being conducted by RSSB. Compared with passengers in in-line seating, those in open bay seating have a greater length of time in the event of an accident before impacting a passenger opposite, allowing a small degree of evasive action to be taken. This is difficult to represent in computer simulation or testing. In the case of table bay seating, tables have proved to be an effective restraint in many accident situations and provide a degree of restraint even when the vehicle rolls over, although minor injuries have occurred as a result of the restraining action. The question of low-back seating has not been considered in the work described in this report because, as a result of research conducted by British Rail early in the 1990s, a specification for crashworthy seating was produced and later incorporated within the current ATOC Code of Practice AV/ST9001. This document specifies a minimum seat height that is sufficient to support the head at its centre of gravity in the event of a longitudinal impact.
SECTION 5

INVESTIGATING SEAT BELTS
5.1 INVESTIGATION OF TWO-POINT SEAT BELTS

In the immediate aftermath of the Ufton Nervet accident, a demand arose for the fitment of lap-belts similar in type to those fitted in many road coaches and aircraft. This aspect of the planned research was therefore brought forward in the programme. The proposed approach to the investigation was set out and subjected to critical debate in a workshop that included experts involved in research for all transport industries, to ensure that the approach was scientific and free from bias towards or against any particular solution.

The tests were undertaken at TRL in a manner that was consistent with tests carried out for other forms of transport.

5.2 TWO-POINT SEAT BELT TEST PROTOCOLS

In order to ensure that the results from the various tests were comparable, permitting valid conclusions to be drawn, a rigorous setting-up procedure was essential. It was essential, too, that the sequence of tests carried out permitted a full evaluation of the effects of occupant restraint by two-point seat belts and of unrestrained occupants. It was also important to consider the differences between a double seat arrangement with only one occupant and a double seat arrangement with two occupants, as the performance of the seat structure, in both restrained and unrestrained occupant situations, would be affected by the total occupant weight supported. A further variant to be considered was the case where a seat was occupied by a restrained person, whilst the seat behind was occupied by an unrestrained person. In this case the seat of the restrained person would effectively be subjected to the double loading imposed by both the restrained person and the unrestrained person.

The severity of injury sustained by a person restrained by a two-point seat belt would be significantly influenced by the stature of the person. It was therefore considered essential for a wide range of seat occupants to be represented in the tests ranging from a small female adult (also approximating to a child of mid-teenage years) to a large male. The ATDs selected were a 5th percentile female (only 5% of the female population being of that size or smaller), a 50th percentile male (50% of the male population being of that size or smaller), and a 95th percentile male (95% of the male population being of that size or smaller).

It was recognised that the seat pitch (the distance between two rows of seats) would have a significant effect on the injury levels sustained in both restrained and unrestrained situations. Accordingly a representative range of seat pitches was included within the test.

Taking all of the above into account a precisely defined test protocol was therefore established (see Appendix I).
5.3 INSTALLATION OF TWO-POINT SEAT BELTS

The installation of the two-point seat belt must ensure that the belt webbing is correctly positioned on the seat occupant. Restraint across the abdominal region is likely to impose unacceptable loads on vital internal organs, leading to serious injury or fatality. The restraint from the belt must therefore be across the bone structure of the pelvic girdle and the positioning of the anchorage point should be determined in order to ensure the location of the belt is correct.

Figure 13, which is taken from the Society of Automotive Engineers (SAE) Document ARP682B, was used as the specification defining the correct anchorage point location for all of the seat belt tests.

Despite the involvement of TRL, with the considerable experience available from their employees, it was decided that the tests must be seen to be credible by an independent validation of the installation. A conscious decision was taken to engage a company of seat belt fitters, the Managing Director of which had been a prominent critic of the railways for not fitting seat belts to trains. The company was a major installer of seat belts in road coaches, with considerable experience of installing seat belts, and the Managing Director had appeared on television supporting the campaign for fitting of two-point seat belts in trains.

It was considered beneficial to engage the company from two points of view. Firstly, such a critic would be ideal in exposing any weakness in the proposed testing, permitting it to be addressed in advance of the testing. Secondly, the experience from installing many seat belts in road coaches, and an extensive involvement in connection with the legislation relating to the fitting of seat belts in road coaches, would be valuable in assessing the integrity of the seat belt installation. Finally it was further agreed that this involvement should extend to witnessing the testing as validation of the integrity of the testing.

5.4 THE TWO-POINT SEAT BELT TESTS

The collision pulse used for the tests had been derived from crash tests carried out by British Rail. The collision between two trains was instrumented and a typical crash pulse was derived for a modern train. This pulse has been carried forward into the ATOC document AV/ST9001. It has been used for a number of years for the crashworthiness testing of new rail vehicle seats.
The test installation comprised a test sled (or trolley) on which were installed three rows of two rail vehicle seats, comprising six in total. These were mounted in a manner which faithfully represented a typical vehicle installation (Figure 14).

In order to ensure repeatability and comparability of the test results the ATDs were installed on the test sled precisely in accordance with the protocol referred to above. All critical positional points on the sled, the seats and the ATDs were measured relative to a single datum point to confirm that the ATDs were seated exactly as required. The positional dimensions were recorded before and after the test in order to determine levels of distortion of the seats and the movement of the ATDs (See also Figure 14).

The tightness of the seat belt across the abdomen of the ATD was adjusted in accordance with the protocol used for testing across the transport industries. Seat belt loading was also measured.

The installation of the two-point seat belts was carefully designed to ensure that its performance was not influenced by the particular design of the seat, which could have distorted the results. Also, the type of seat belt anchorage used ensured that stiffening of the seat was not required. It was agreed that installation in a rail vehicle could be designed in such a way that excessive loads transferred to the seat frame by the seat belt anchorage could be avoided and it was therefore concluded that the complete installation was truly representative of a practical rail vehicle installation.

The completed installation was then submitted to the critical validation referred to above and fully endorsed.

5.5 TWO-POINT SEAT BELT TESTS – INJURY CRITERIA

The tests were undertaken and video records were taken to supplement the data collected from the instrumented ATDs. Whilst there were many channels of injury information recorded, it was very evident that the two key injury criteria were to be those related to the head and neck.

From work already undertaken under RSSB research, the criteria in relation to the head and neck had been determined to be the Head Injury Criterion (HIC) and the Neck Injury Criterion (NIJ) respectively.
The HIC measure is an assessment of the magnitude of an impact to the head taking account of the high accelerations of the head and the duration of those high accelerations. In the rail industry an acceptable limit for HIC of 500 has been applied for several years because it was considered that, above this level, passengers may not be in a condition to make conscious decisions to escape from a threatening situation (Figure 15).

The NIJ, is more comprehensive than the previous neck criteria used for rail. It combines four individual measurements into a single comparable value. NIJ is an assessment of the effect on the neck of forward or rearward rotation of the neck in combination with an assessment of the compression or stretching of the neck. Thus a single overall value is computed. An acceptable limit for NIJ of 1 has been applied in common with its usage outside the rail industry (Figure 16).

5.6 TWO-POINT SEAT BELT TEST RESULTS

The tests were conducted using the three different sizes of ATD and repeated for seat pitches of 752mm, 800mm, 830mm and 900mm to cover the range of seat pitches typically found on UK rail vehicles. Combinations of restrained and unrestrained occupants were also tested to cover the full spectrum of alternative combinations that may occur in a vehicle.

It was very evident that, in the case of the restrained seat occupant, the point of impact with the seat in front varied very considerably as a function of the relative measurements of the height of the head above the seat cushion and the distance to the seat in front (or seat pitch), as is illustrated in Figure 17. It is evident that, for a given size of person, the larger the seat pitch, the further the restrained passenger will rotate before impacting the seat in front. In each case, however, the forward motion is halted by head impact. A similar effect is also evident where the seat pitch is fixed and the height of the seat occupant varies. The smaller the seat occupant, the further the restrained passenger will rotate before impacting the seat in front and the forward rotation is halted by head impact.
Consideration of the videos indicated a very violent reaction on the neck in the case of the restrained seat occupant, which was subsequently confirmed by the measurements recorded.

Figure 18 illustrates the very significant rotation of the neck under the impact, with no such corresponding rotation in the case of the unrestrained occupant.

A further feature that became evident by examination of the video was the significant amount of distortion of the seat back under impact from the unrestrained occupant of the seat behind. The distortion of the seatback is desirable to prevent serious upper leg injuries to the rear seat occupant. For the restrained occupant, however, this distortion above the seat belt anchorage point resulted in the seat back being pushed into the lower spine region of the restrained occupant, with a severe tightening of the seat belt across the top of the thighs.

The head rotation can be more clearly seen also in Figure 19, which is the case of the 5th percentile female. It can also be seen that, with the smaller stature, the unrestrained occupant of the seat behind, impacts the seat in front closer to a standing position, with the impact load spread more evenly down onto the torso as well as the head. Thus the neck is spared a more significant impact compared with the restrained case. The measurements recorded confirmed the impression gained from the video, that the restrained occupant suffered a higher level of injury than the unrestrained occupant. This relative severity was reflected throughout the series of
tests. As expected, the knee intrusion experienced with the 95th percentile male did not arise with the 5th percentile female as the intrusion is dependent upon the mass of the unrestrained person impacting the seat in front.

The extensive series of tests yielded very clear results. It was very evident that the head impact was not a cause of concern, all measured values being within acceptable limits for restrained and unrestrained occupants. However, as indicated above, the neck injury levels gave cause for concern. A sample of results for NIJ relative to seat pitch, for the 50th percentile male, is given in Figure 20. It should be noted that the seat pitch is not in numerical order, but rather in order of the defined test sequence in the protocol.

![Figure 20](image.png)

The results from the testing of the two-point seat belt applications clearly indicated that restraining occupants with this type of belt would be likely to increase the injury levels compared with injuries sustained by an unrestrained occupant impacting a crashworthy seat.

### 5.7 THREE-POINT SEAT BELT TEST PROTOCOLS

With the three-point seat belt installation an additional anchorage point was required adjacent to shoulder level. It was necessary also for this anchorage point to be varied to give the ideal position for the occupants of different stature. It was not possible to provide mountings on the vehicle body shell for those seats not adjacent to a bodyside, necessitating attachment to the top of the seat back. This attachment would apply a potentially very significant load to the top of the seat back that was not present with the two-point seat belt installation. The additional load-bearing point on the seat was likely to be particularly significant in the case where a seat was occupied by a restrained person, whilst the seat behind was occupied by an unrestrained person, as the one seat would support the weight of both passengers in an impact. It was agreed that an additional test should be undertaken at the
commencement of the sequence to determine whether the seat would require to be stiffened in order to support these additional loads.

As in the case of the two-point seat belt tests a test protocol was deemed necessary to ensure that the results from the various tests were comparable between themselves and with the results of the two-point seat belt tests. This was deemed essential in order to permit valid conclusions to be drawn. The same rigorous setting-up procedure was used and a sequence of tests was agreed that would permit a full evaluation of the effects of occupant restraint by three-point seat belts and of unrestrained occupants. It was necessary to include tests with unrestrained occupants as the injury levels sustained by both the unrestrained and restrained occupants would differ from those in the two-point seat belt tests, the loading on the seat back having changed. The sequence of tests undertaken with regard to two-point seat belts was to be repeated in order to compare the changes to injury levels.

Taking all of the above into account a precisely defined test protocol was again established (see Appendix J)

5.8 INSTALLATION OF THREE-POINT SEAT BELTS

The installation of the three-point seat belt must ensure that the lap section of the belt webbing was correctly positioned on the seat occupant to avoid imposing restraint loads on the vital internal organs of the abdominal region. The lower anchorage points were therefore set up again in accordance with SAE Document ARP682B, illustrated in Figure 13.

The top mounting took the form of three alternative locations, permitting appropriate selection for each size of ATD in order to optimise the belt restraint in accordance with well established criteria used in other forms of transport.

As a result of the publishing of the two-point seat belt report, RSSB was approached by a restraint specialist company, offering assistance in the research. The Technical Director of the company provided independent assessment of the type of seat belt selected for the test and the installation.

Following the consultation it was agreed that inertia mechanisms would not be used during the tests as the additional movement permitted during operation of the inertia mechanism could result in more severe injuries. A fixed belt was deemed to provide the most optimistic injury benefit.

The restraint specialist company had its origins in the founders of one of the original manufacturers of seat belts. The involvement of its founder in the early development of seat belts, the development of legislation and the more recent development of specialised restraint devices provided a wealth of experience that was seen to be very valuable in independent evaluation and the company’s Technical Director witnessed testing as part of that validation.
5.9 THE THREE-POINT SEAT BELT TESTS

The same seat types, seat pitches and collision pulse used for the two-point seat belt tests were used for comparability of results.

In order to ensure repeatability and comparability of the test results the ATDs were again installed on the test sled precisely in accordance with the protocol referred to above. All critical positional points on the sled, the seats and the ATDs were measured relative to a single datum point to confirm that the ATDs were seated exactly as required. The positional dimensions were recorded before and after the test.

The completed installation was then submitted to the critical validation referred to above and fully endorsed.

5.10 THREE-POINT SEAT BELT TESTS – INJURY CRITERIA

The tests were undertaken and video records were taken to supplement the data collected from the instrumented ATDs. Whilst many channels of injury information were again recorded, the head and neck injuries were particularly monitored for comparability with the two-point seat belt tests and to permit an assessment of the improvement or otherwise.

5.11 THREE-POINT SEAT BELT TEST RESULTS

The first test was conducted using four 95th percentile male ATDs in order to determine whether existing seats could withstand the additional seat belt loads, particularly at the top of the seat back. The test conclusively demonstrated that seats would need to be stiffened to support the combined load of a restrained and an unrestrained person. Accordingly the seats were modified to a stiffness level commensurate with the load to be restrained. All seats used in the remaining tests, except those used as the initial starting point for unrestrained occupants, were stiffened in the same way.

The tests were conducted using the three different sizes of ATD and repeated for seat pitches of 752mm, 800mm, 830mm and 900mm to cover the range of seat pitches typically found on UK rail vehicles. The 950mm case was not repeated as it was considered more could be learned from additional tests undertaken to explore the effect of inertia-reel seat belt types. Combinations of restrained and unrestrained occupants were also tested to cover the full spectrum of alternative combinations that may occur in a vehicle.

Figure 21 indicates the significant findings from the three-point seat belt comparisons. Firstly, comparing the results of restrained (three-point belted) and unrestrained occupants (unbelted with non-stiffened, crashworthy seats as used in the two-point seat belt work), it can be seen that the use of three-point seat belts reduced the projected neck injury levels (measured as NIJ values), although in both situations restrained and unrestrained occupants received injuries well within the acceptable criterion for NIJ.
Further comparison indicates that stiffening the seats, for the purpose of seat belt anchorage, results in a very significant increase in the injuries to unacceptable levels in the case of unrestrained occupants.

The results from the testing of the three-point seat belt applications indicated that restraining occupants with this type of belt would be likely to reduce the injury levels compared with injuries sustained by an unrestrained occupant impacting a crashworthy seat, although both were within acceptable limits. However, the stiffening required for the seat belts would significantly increase the injury levels for unrestrained occupants well beyond acceptable limits. It was evident that, with the stiffened seat, the level of injury sustained by the unrestrained occupant was dependent upon whether the weight of the occupant was sufficient to deflect the seat in front. The lighter the occupant, the less the deflection of the seat in front and the more severe the injury, as seen in the two high points of Figure 21 (both 5th percentile female cases).

HIC levels measured for unrestrained occupants were well within tolerable limits with crashworthy seats, and mainly tolerable for stiffened seats.
SECTION 6

SEAT BELTS AND LOSS OF SURVIVAL SPACE
6.1 LOSS OF SURVIVAL SPACE

During the course of linking injuries with the damaged condition of the vehicles, it became evident that few injuries had occurred in locations where survival space appeared to have been lost and fatalities would have been expected. On further investigation it became evident that there were a significant number of seat locations at which survival space had been severely reduced or lost.

This situation was completely unexpected and was initially assumed to be due to circumstances unique to Ufton Nervet. However, it was considered prudent to investigate the information obtained regarding the previous six accidents. The Ladbroke Grove accident was then excluded from the consideration since the structural collapse of the leading Thames Trains unit rendered such a comparison impossible. The evidence from these accidents was similar to that from Ufton Nervet. The results led to the conclusion that in such cases of severe vehicle body shell impact distortion, those sitting at such locations were thrown clear prior to the loss of survival space. Attachment of the seats to the bodyside on vehicles involved in the accidents, may have assisted this.

In the face of this evidence a further analysis of the effective benefits of seat belts was undertaken. The following simple assumptions were made:

1. It was assumed that all passengers who were subjected to involuntary exit, and who suffered fatal injuries, would have survived if wearing seat belts. These assumed fatal injuries would not have resulted from the wearing of seat belts and that involuntary exit would have been prevented in every case. Equally, in at least one case, the passenger's fatal injuries were inflicted by an object penetrating the window prior to involuntary exit and the fatality would not have been prevented by the use of a seat belt. Neither of the assumptions was likely to be true for all cases, but they deliberately favoured the argument for seat belts.

2. It was assumed that all passengers occupying seat locations where survival space was lost would have lost their lives, as seat belts would have prevented them from being thrown clear of the intrusion. Assessing the vehicle damage indicated that this assumption was realistic.

3. It was assumed that all other passengers who had not suffered involuntary exit, and who had been located in seats where survival space was not lost, would not have suffered more adverse injuries from seat belts. From the testing above it was seen that passengers restrained by two-point seat belts would probably have been more seriously injured and that unrestrained passengers would have been more seriously...
injured if seats had been stiffened to accept three-point seat belts. This assumption deliberately favoured the argument for seat belts.

In the six accidents considered there were 11 fatalities in cases of involuntary exit (see table 1, but excluding Ladbroke Grove) and it was assumed that all 11 would have survived if wearing seat belts. In total there were 220 seats at which survival space was seriously reduced and probably lost. This total was rationalised to reflect the passenger densities on the trains and reduced to 88 occupied seat locations with loss of survival space. On the basis of the assumptions above, ignoring likely increases in injuries to other passengers, the installation of seat belts could potentially have saved 11 lives and caused 88 to be lost. If the outcome had been marginal, then the issue would have been discounted, but it was not marginal. Even if all 19 cases of involuntary exit had resulted in fatalities, the comparison would have indicated 19 lives potentially saved, with 88 lives potentially lost – still far from a marginal case. Clearly in the development of solutions that could save lives, the potential of such solutions to cost lives must be considered too.
SECTION 7

PERFORMANCE OF WINDOWS
7.1 WINDOW TYPES

Windows were seen to be a principal route through which passengers experienced involuntary exit during an accident, 80% of the fatalities due to involuntary exit being via windows. This was hardly surprising since the glazed area was the weakest part of the vehicle body shell. The adoption of stronger windows that would resist impact was potentially an alternative solution to this problem. The alternative solution to be investigated was the fitting of laminated glass instead of toughened glass.

Toughened glass is a term that identifies glass the properties of which have been modified by heat treatment to enhance its toughness. Such glass, when subjected to impact, shatters into small ‘dices’ that are considered to be relatively non-injurious.

Laminated glass is a term that identifies glass that actually comprises two sheets of glass separated by a resilient interlayer. With this construction, optimum properties can be developed by varying the type of glass used in each of the two sheets and varying the material used for the interlayer. Thus, whilst individually, the sheets of glass may be less tough than the toughened glass, as a composite the result can be significantly more resistant to impact. The strength for containment in a laminated glass unit, and the resilience of the impacted laminate, are predominantly derived from the interlayer.

The material commonly used as the interlayer in double glazed units for trains, polyvinyl butyl (PVB), is susceptible to the effects of temperature, particularly at high and low temperatures. Under the more extreme conditions of the ambient temperature range experienced commonly in the UK, the performance of the interlayer is largely negated. In order to counter this degradation of performance, the laminated glass is usually installed as the inner pane of a double glazed unit, at which interface the temperature is closer to that of the vehicle interior, and toughened glass is used for the outer pane.

The need to install the laminated glass as the inner pane may not apply where alternative interlayer materials are being used. However, the requirements for rescue, referred to later, may still result in the installation of the laminated glass as the inner pane.

7.2 EVOLVING REQUIREMENTS FOR WINDOW PERFORMANCE

Early British Rail vehicles, designated Mark I rolling stock, had predominantly been fitted with single glazed units of toughened glass. As indicated above, prior to the late 1980s involuntary exit during an accident had not been a significant feature of rail accidents. With the introduction of more modern stock, the Mark II vehicles in the 1960s and the Mark III / HST vehicles (such as those involved in the Ufton Nervet accident) in the 1970s, double glazed windows were installed, but this was principally to give better thermal and sound insulation to counter the effects of the higher speeds. Involuntary exit
was still not a significant factor and windows therefore continued to be of
toughened glass.
With subsequent accidents, moving into the 1990s it became evident that
involuntary exit was emerging as a more significant injury phenomenon, in
response to which requirements for the fitting of laminated glass were
developed, culminating in the Railway Group Standard GM/TT0122 in June
1993: “Structural Requirements for Windscreens and Windows on Railway
Vehicles”. This standard mandated laminated glass for all vehicles ordered
from 1 September 1993, to reduce the risk of involuntary exit. Only windows
designated for emergency egress were exempt. The requirements of this
standard are largely in the current requirements for rail vehicle bodyside
windows defined in Railway Group Standard GM/RT2456 Issue 2 April 2002,
“Structural requirements for windscreens and windows on railway vehicles”.
The specific requirements are explained in Guidance Note GM/GN2560.

Railway Group Standards do not as a matter of course mandate things
retrospectively since, in the case of the majority of updated requirements, the
cost would be prohibitive and the benefit outweighed by the cost. Standards
only apply retrospectively where specifically stated in the individual standard
concerned. The retrospective fitting of laminated glass was not mandated in
the issue of GM/RT2456 (see further comments below).

Toughened glass window units typically comprise two panes of glass with an
air-gap between them. Rail vehicles fitted with double-glazed toughened
glass units, such as the HST, have units that are typically 18mm thick in total.

The laminated glass units comprise one pane of toughened glass, an air-gap
and a second ‘pane’ of glass comprising a plastic interlayer sandwiched
between two layers of glass. In the latest vehicles typical overall thicknesses
lie within the range of 26 to 30mm. This represents an increased thickness in
the order of 55% and potentially an increase in weight of a similar order. It
had therefore been considered that retrospective fitting of laminated glass in
vehicles designed for windows with a total thickness of less than 20mm would
not be feasible on account of both the increased thickness and weight.

As a result of Ufton Nervet, investigations had been initiated into the feasibility
of developing a laminated window within current vehicle constraints using the
latest materials and technology. This investigation was therefore absorbed
into the research programme in the recognition that the appropriate
performance requirements needed to be determined rather than merely a
change to laminated glass.

7.3 THE SECONDARY ROLE OF WINDOWS

The secondary safety role of windows was recognised as being complex.
Windows could be used as an optional escape route in an emergency or as a
means of access during rescue operations. However, windows were
potentially the weakest part of the vehicle body shell surrounding the
passenger and were vulnerable to being broken in an accident, with
involuntary exit of passengers resulting. Thus such requirements as containment, escape and rescue would appear to be in conflict. A number of the six accidents investigated illustrate these different secondary functions.

The accident at Potters Bar, during which the last vehicle of the train was derailed, jack-knifed and rolled, ultimately sliding along the station platform, resulted in a number of involuntary exits with fatal results. The derailment was compounded by a balance weight from the overhead wire system entering through a bodyside window which, in turn, led to an involuntary exit. The accident indicated that greater protection against penetration from outside during a derailment was an important consideration as well as the prevention of involuntary exit.

The Southall accident, during which one vehicle was severely buckled by impact with a line-side structure, resulted in such pictures as Figure 24 being widely publicised. The picture suggested that entry through windows in the vehicle body were seen by the rescue services as the way to gain access to the injured and trapped occupants of the vehicles. This suggested that windows were a key means of access for the emergency services attending a rail accident.

There had been much publicity also regarding the use of windows by passengers for escaping a vehicle after an accident (Figure 25). Emotive pictures from previous accidents had provided very graphic images in the minds of travelling passengers and the public in general. After the Ufton Nervet accident many passengers attempted to escape from the vehicles via the windows.
The research therefore investigated the escape routes used in all seven of the accidents identified and the results of the investigation are summarised in Figure 26.

It can be seen that approximately 27% of the passengers at Ufton Nervet exited the train via windows after the accident; although in every case there were alternative and safer means of exit, with nobody needing to exit through a window (see Appendix K). However, in the same accident four passengers were subjected to involuntary exit through windows during the accident and were fatally injured. Serious injury also resulted from partial exit during the accident.

The numbers of passengers exiting via bodyside windows at Hatfield was exceptional, as indicated in Figure 26 due to the number of vehicles remaining upright and the controlled evacuation undertaken. The increased use of windows subsequent to the Ladbroke Grove accident, evident in Figure 26, was believed to have been heavily influenced by the visual images and graphic accounts published after the Ladbroke Grove accident and at the time of the subsequent Inquiry. In their witness statements, and in investigatory interviews, many passengers indicated this was the reason for their actions.

The information identifying the percentages of passengers exiting via the doors after the same accidents indicates a consistent usage of doors until after Hatfield, as seen in Figure 27. As already indicated there were particular circumstances that resulted in the escape routes selected at Hatfield, at which an orderly evacuation of 80% of the passengers via the doors or the inter-vehicle connection (where vehicles had separated in the accident) was achieved. Nevertheless the effect of Ladbroke Grove can again be seen in the dramatic reduction in those exiting via the vehicle doors at Great Heck, Potters Bar and Ufton Nervet.
It was vital for the research to identify the reasons for the escape route chosen by passengers since unavailability of an alternative route would be critical to any strategy for containment or escape. The information for the Ufton Nervet accident was therefore extensively reviewed (see Appendix L). It was clear from the witness statements and the interviews that passengers choosing windows as the escape route had been heavily influenced by previous press articles relating to Ladbroke Grove, not by the needs of the situation. The information obtained regarding the other six accidents was also extensively analysed, together with a review of press cuttings relating to the accidents and which reported passenger reactions. The information indicated similarly that passengers had become conditioned by publicity surrounding the Ladbroke Grove accident, the subsequent inquiry and the inquest, to consider windows as the first means of escape.

7.4 PROTECTION FROM EXTERNAL OBJECTS

As has been indicated above, a review of the accidents identified the need to protect passengers from external objects penetrating the windows during the course of an accident as well as the possibility of the window being penetrated from inside the vehicle. During the course of an accident, when the train is derailed, there is a potential danger that components may be displaced from the train or the object with which it has collided. Such components or other objects may become airborne and windows are the most potentially vulnerable area of the vehicle where penetration may occur. Equally, in the case of derailment without a collision, there is the possibility that smaller objects or ballast may...
impact the windows.

The current Railway Group Standard already requires windows to be tested for impact resistance against flying ballast and such tests were deemed to be adequate for the small items. However, no test was specified to replicate the possibility of protection against larger items. As part of the research collaboration between RSSB and the American Federal Railroad Administration (FRA), details of the FRA testing of windscreens emerged in which a solid steel sphere was used to replicate a heavy object impacting windscreens. Consideration of the test indicated that the spherical object would be representative of the mass of objects that could impact the side windows of a rail vehicle in the event of a collision and derailment. The solid steel ball had a mass of 5.45 kg (12 lb), approximating to the size and mass of a shot putt. Consideration was given to a number of possible accident situations in order to determine probable angles at which the object could strike the window. It was recognised that an object striking the train at an acute angle was unlikely to cause much damage as it would deflect off again. An optimised angle of strike was agreed.

The case considered for the impact resistance of the window was that of a train travelling at 100 mph (160 km/h) which, taking the equivalent direct component of the strike on the window, was equivalent to a perpendicular speed of 20 mph (32 km/h) (See Figure 30).

![Figure 29 The Test Sphere](image)

### Figure 29 The Test Sphere

![Figure 30 Equivalent speed of impact](image)

### Figure 30 Equivalent speed of impact

#### Speed of vehicle = 100 mph (160 km/h)

Assumed angle of attack = 11°

Equivalent speed onto vehicle side = 20 mph (32 km/h) to avoid deflection

7.5 PROTECTION IN ROLL-OVER

The second aspect of the protection was to ensure that, in the event of a rail vehicle overturning (the roll-over case) the window would withstand the impact of a passenger falling against it. Computer simulation of a number of cases highlighted the different trajectories that would result from a vehicle rolling with the bogie attached and a vehicle rolling with the bogie detached. This difference is illustrated in the Figure 31.
Extensive computer simulations of vehicles rolling over with bogies attached and detached have given a clear understanding of the possible effects on passengers within the vehicle and the impact loads that windows must withstand in such situations to maintain containment (see Figure 32). This information permitted the identification of the worst case of a passenger falling against a window in the two basic roll-over cases indicated above. This case has been included in the test scenarios and proposed for inclusion within an enhanced specification for windows.

Early tests utilised the BS6206 test which was designed to assess the suitability of glass for interior doors of static premises, particularly addressing the concern that children may be seriously injured walking into glazed doors. The test comprised a pendulum attached to which was a bag filled with lead shot, designed to replicate a body impacting the glass. Subsequently the BS6206 test rig was modified, utilising precisely defined pneumatic tyres at a specified pressure in order to give greater repeatability of results. Such a test rig was manufactured with the pendulum arc increased to give the appropriate energy levels determined by the computer simulations referred to above on impact with a window under test.

The test rig was designed to accommodate a window of the size commonly used in High Speed Trains, to give comparability with the early tests carried out on such a unit.
The pendulum arc was designed to be adjustable to permit various conditions to be simulated if required. The impacting mass could also be adjusted to suit test conditions.

The double glazed windows tested were installed with the inside pane towards the impacting mass, representing an impact from a falling passenger during roll-over.

Figure 33 comprises two photographs showing the pendulum rig in total and a close-up of the mounted window unit installed in the rig. The window was mounted on end in order to give a more appropriate arc onto the glass. Protection was required at the rear of the rig to catch shattered glass.

Figure 33 The window test rig

7.6 DEVELOPMENT OF A LAMINATED WINDOW FOR CONTAINMENT

Having identified a level of performance that was considered to provide an appropriate level of containment, it was necessary to establish that a window could be developed to meet that performance within the constraints of a practical vehicle installation. A further objective was to develop such a window within the constraints of existing vehicle designs, particularly those of High Speed Trains (HST) similar to the vehicles involved at Ufton Nervet.

As indicated in section 7.2 above, following the Ufton Nervet accident, First Great Western had initiated exploratory work with Independent Glass, a manufacturing company, to develop a suitable double-glazed window unit with laminated glass. This early work was then taken forward within the research project to ensure that the unit would meet the test regime described above, whilst remaining within the constraints of the HST vehicles to facilitate direct replacement if deemed appropriate on conclusion of the research.

7.7 LAMINATED WINDOW - INITIAL TEST RESULTS

Initial tests were carried out to establish that the newly developed double glazed unit met the current requirements of Railway Group Standards specified for laminated glass, without conformance to which the fitting of the new unit to trains in service would not be permitted.

The unit was successfully subjected to the impact test defined in Railway Group Standard GM/RT2456, which represents impact from ballast, or a small object, at a speed of 100 km/h, (62.5 mph).
The unit was further subjected to the point load test required by GM/RT2456 in which a load of 0.8kN is applied at points over the unit to determine whether the unit could support the weight of a 95th percentile male standing on the window of an overturned vehicle. As shown in Figure 34, the unit was tested by lowering a weight of 0.8kN, mounted on a square carrier frame having a contact area of 0.1m x 0.1m, onto the glass.

The unit was then subjected to a pressure of 6kPa uniformly distributed over the full face of the glass to represent a number of people crushed against the window in an accident. Both tests were successfully achieved, thus meeting the current mandatory requirements applicable to rail vehicle windows. These do not include any assessment of the roll-over case.

One further test was undertaken in order to demonstrate that a broken window would not be vulnerable to the effect of a passing train. This was simulated on the purpose-designed test rig at DeltaRail. A window unit was first impacted by a sharp instrument to break the outer toughened pane of glass. The unit was then subjected to 25 pressure pulsations, simulating the effect of a passing train’s slipstream. This was completed successfully without a single particle of glass being ‘sucked’ out.

The successful completion of the above tests, proving conformance to all current mandatory requirements, was a vital preliminary to the containment trials on the new type of laminated window unit since failure to meet existing requirements would have prevented its future use in service.

7.8 A NEW TEST SUITE SIMULATING AN ACCIDENT SEQUENCE

Many tests were carried out during the research to establish the effectiveness of the individual tests and to explore in depth the performance of the windows under such test conditions. Windows were successfully subjected to multiple steel sphere impact tests without penetration and subjected to multiple pendulum tests, representing several 95th percentile males, without loss of containment. These individual tests were then combined into a single test sequence simulating a realistic accident scenario, to which the newly developed unit was subjected. The test was established to simulate the following sequence of events:

1. A derailed vehicle with the window impacted from the outside by a large piece of debris – the test identified above using the large steel sphere.
2. The vehicle then rolling over onto its side and a passenger falling from the highest seat onto the window already impacted in step 1.
3. The vehicle having rolled, and having finally come to a standstill, a 95th percentile male walking along the upper surface of the overturned vehicle and stepping onto the same window.

7.9 LAMINATED WINDOW TEST RESULTS (NEW REQUIREMENTS)

For the test suite the double-glazed window unit was installed in an actual HST window frame, using the standard gasket. The window frame was then installed in a steel panel fully representative of the vehicle installation. The complete assembly was then fitted into the respective rigs for carrying out the full suite of three accident scenario tests as defined above.

The penetration test was undertaken by dropping the steel sphere from a predetermined height to give the required speed on impact of 20 mph. The toughened glass pane was uppermost simulating an impact from outside the vehicle. Photographic and video evidence was recorded, including high-speed video, in order to permit full evaluation of the performance subsequent to the test. Whilst the toughened pane of the developed unit shattered locally to the impacting sphere, the laminated pane fully withstood the impact as can be seen from Figure 35. The video clearly demonstrated the reaction of the laminated pane to be similar to a trampoline, with the sphere bouncing several times before coming to rest.

The same double glazed unit was then subjected to the pendulum test to simulate the second phase of the representative accident sequence referred to above. The window unit was mounted on end in the pendulum rig and the pendulum was set for the energy level identified from the computer roll-over simulation.

The pendulum was released and impacted the laminated pane of the double-glazed unit, simulating an internal impact from a passenger falling across the full width of the rolled vehicle. The laminated glass, already having been subjected to the large impact test, was further damaged, but there was no penetration of the laminated glass. The ability of the laminated glass to flex resulted in the laminated glass impacting the outer toughened glass, ejecting much of the toughened glass shattered during the previous impact test. Figure 36 shows the results of the test, the areas where the brick
wall can be clearly seen being those where the toughened glass has disintegrated and fallen away from the far side of the unit. Full containment was maintained.

The final stage of the sequence was then undertaken in which the same double-glazed unit that had survived the previous two test stages was subjected to the 0.8kN containment test. The window unit was transferred to a horizontal rig and the 0.8kN weight was lowered onto the surface of the glass. The glass fully supported the weight, demonstrating again that containment had been maintained and that, post accident, the window was capable of supporting the weight of a large male passenger.

7.10 POINTS ARISING FROM THE TESTS

The research did not merely consist of a single series of tests as described above; many tests were undertaken to explore and compare the relative performances of laminated and toughened window units. During the course of these exploratory tests the effect of bonding glazing units to vehicles was also assessed. Where bonding was used it was evident that the surface preparation, the installation procedure and the conditions of curing needed to be properly controlled for the installation to achieve maximum integrity. Where bonding was not used, and where the installation of the double-glazed unit was via a gasket (such as in the case of HST windows), it was vital that the gasket was correctly installed and that the mechanical securing of the unit into the window frame was in good order. Containment depends upon the integrity of the fixing of the double-glazed unit into the vehicle just as much as it depends on the ability of the laminated glass itself.

Although not specifically a part of the research, it was recognised that the method of installation on the HST window unit gave a very high degree of fixing integrity.

7.11 TOUGHENED WINDOW TEST RESULTS (NEW REQUIREMENTS)

Having demonstrated that it was possible to achieve a high level of containment within the constraints of existing vehicles, the existing type of double-glazed toughened glass window was subjected to the new tests by way of direct comparison.

Firstly the unit was subjected to the penetration test using the solid steel sphere. Whilst the laminated unit had been tested with an impact speed of 20 mph, it was decided that the initial test of the toughened glass unit should be conducted with an impact speed of 12 mph. This represented a reduced energy input of only 36% of that used for the laminated glass unit.

Despite the reduction of 64% in the impact energy, the impacting sphere fully

---

*Figure 37 Penetration test (Toughened glass)*
penetrated the unit with no evidence of any resistance at all, as indicated in Figure 37.

The benefit presumed previously for toughened glass was that, under conditions of impact, the glass would shatter into a large number of small dice which would have little injurious impact on passengers. In these tests, the use of high-speed video was very instructive in investigating the reality.

Figure 38 is the view taken from under the double-glazed unit (the passenger’s side) showing the glass rapidly separating from the frame and being propelled into the vehicle interior. It can be clearly seen that, although the glass shatters into small dice, the impact is so rapid that the dice break away in large clusters which approximate to large shards of glass. The potential to injure passengers is thus even greater than was anticipated. Not only did the glass present a hazard to anyone on the inside of the vehicle, but in the midst of the large shards of glass seen in Figure 38 is the solid steel sphere that broke the window, entering with undiminished speed. The results obtained with the double-glazed toughened glass window unit demonstrated that such a window provides no degree of resistance to penetration of external objects, with negligible protection for passengers.

Clearly the window unit could not be subjected to the pendulum test, the glass having totally failed. A new double-glazed toughened glass window unit was therefore tested. Again, no resistance to the impact was witnessed and both panes of the window unit were totally shattered.

From the tests carried out on the double-glazed toughened glass unit it was evident that such a window unit would neither provide passengers with any significant level of protection against penetration by articles impacting the window from outside, nor provide any significant levels of containment for passengers impacting the windows from inside.

It was concluded that double-glazed window units comprising only toughened glass were incompatible with requirements for containment of passengers. This leads to the consequential conclusion that the provision of windows that are breakable for escape leaves passengers vulnerable to penetration of objects from outside in an accident, or vulnerable to involuntary exit if they impact a window.
SECTION 8

A SUMMARY REVIEW OF CONTAINMENT
8.1 SUMMARY OF THE RESULTS OF THE CONTAINMENT RESEARCH

From the research described in the foregoing a number of points have been established:

1. Involuntary exit has become a significant cause of fatality in more recent years, particularly in accidents at high speed. The percentage of fatalities due to involuntary exit increased from less than 5% (1973-1983) to almost 45% (1983-2004).

2. There are two potential ways to reduce such fatalities, namely restraining passengers to their seats (using seat belts) or providing windows that are able to contain passengers in an accident.

3. Current seats are designed to deform under impact in a manner that cushions passengers to reduce injuries. The performance requirements are defined in the Code of Practice AV/ST9001.

4. The wearing of two-point (lap) seat belts has been shown to double the level of passenger injuries when comparing restrained passengers with unrestrained passengers cushioned by crashworthy seats.

5. The tests demonstrated that the above type of crashworthy seats would need to be strengthened to support the loads imposed by three-point seat belts in an accident and that the crashworthy performance would be eliminated in doing this.

6. The wearing of three-point (lap and diagonal) seat belts has been shown to reduce passenger injuries by approximately 40% when comparing restrained passengers with unrestrained passengers cushioned by crashworthy seats to current requirements as defined in the Code of Practice AV/ST9001. However, the injuries to both restrained and unrestrained passengers were well within tolerable limits, not exceeding 60% of the tolerable limit.

7. Seats strengthened to support seat belt loads would, on average, almost double the level of injury sustained by unrestrained passengers compared with those unrestrained in crashworthy seats.

8. Accident data has indicated that, in areas where survival space was lost during accident impacts, passengers were thrown clear. Restraining passengers in such areas would have resulted in an increase in fatalities, preventing passengers from being thrown clear (in rail vehicles there is room to be thrown clear, unlike in road vehicles). The data indicated that for each passenger in the six accidents considered (11 passengers in total) whose life may have been saved from fatal involuntary exit by seat belts, eight passengers (88 in total) would have been likely to have lost their lives being restrained in an area losing its survival space. The disadvantage is not marginal.
9. In some cases involuntary exit occurred only after fatal injuries had already been inflicted by objects penetrating the window from outside (such as the accident at Potters Bar), during the course of an accident; an injury mechanism that seat belts would not address.

10. Seat belts would not prevent partial ejection of passengers seated adjacent to the downside window of an overturned and sliding vehicle. Entrapment through partial exit of such a vehicle would be likely to result ultimately in total exit.

11. Windows have been broken in rail accidents as a result of either impacts with objects from outside the vehicle, such as accident debris and adjacent trackside equipment, or impacts with passengers from inside the vehicle.

12. Tests have demonstrated that, whilst toughened glass windows facilitate passenger escape in an incident, they provide negligible resistance to impacts from external objects during a derailment or accident and negligible containment of passengers in an accident.

13. Tests have demonstrated that windows using laminated glass will provide resistance against external impacts and involuntary exit of passengers. They will provide passenger containment and significantly increased protection against penetration by, and injury from, external objects.

14. A new suite of tests has been developed to appropriately simulate a realistic accident sequence in order to assess the containment capability of window designs. This suite of tests simulates an external impact from accident debris, followed by internal impact from a passenger, followed by a large passenger standing on the window (as in the case of an overturned vehicle).

15. Tests have demonstrated that it was possible to develop a laminated glass window with the ability to successfully pass this suite of tests, whilst remaining within the size constraints of existing vehicle designs.

It is important to note that in carrying out the above research no consideration has been given to the effect of the percentage of passengers who may wear seat belts (take-up rate) or of any commercial implications. The research was focused on identifying the means of reducing injuries due to involuntary exit.
SECTION 9

ESCAPE AND RESCUE
9.1 ESCAPING FROM A VEHICLE IN AN ACCIDENT

In the aftermath of an accident passengers will react according to what, in their minds, is the perceived risk. This risk may result from the following:

- A rapid evaluation of the situation (which may be informed or not),
- Recollections of publicity surrounding previous accidents,
- Information communicated by fellow-passengers (informed or not),
- Formal instructions given at the time.

Whilst such a perceived risk may differ widely from the real risk, nevertheless in the minds of the passengers it is the real risk and will determine the passengers' behaviour. Whilst outside the scope of this consideration, it is evident that there are a number of approaches to the situation which include:

- Recognize that passengers will react in accordance with their perception of the risk and accommodate such reactions,
- Discourage reactions that are known to increase the overall risk,
- Develop designs or protocols that would be more likely to align the perceived risk with the real risk,
- Seek to inform or educate passengers regarding the most appropriate actions in the various eventualities and the risks related to inappropriate actions.

The desire to escape is not related to the need to escape. The threat to life or of serious injury only arises when there is a need to escape, not when there is merely a desire to do so. Equally the risk to passengers remaining on board a rail vehicle after an accident is not primarily related to whether they are capable of getting out, but whether they need to get out. If there is no need to get out, then there is no risk of injury associated with being unable to get out unaided. Only when there is an urgent need to get out, such as in the event of fire, does the ability of people to escape from the vehicle become critical. There are two factors affecting the ability of people to escape from a vehicle: the incapacitation of people through injury and the incapacitation of the vehicle through damage. Both are significant in this consideration. A third, where the method of opening doors for escape is not understood in the aftermath of an accident, only becomes significant where the ability to escape is preserved.

The research investigated the ability of people to exit the trains after an accident. This was vital in order to permit an assessment of the risk to passengers presented by the performance of features of the vehicle. It was also vital to permit an assessment of whether injuries or fatalities could have occurred because escape from a life threatening situation was urgent but impossible to achieve in the time. The impediment to exit may have been caused by incapacitation of the person or the vehicle, or through lack of adequate provision for escape. Whilst the six accidents could not be taken as comprehensively covering the accident scenarios that could occur, the individual vehicle end states resulting from those accidents were representative of the likely vehicle end states from a very wide range of accident scenarios. It was possible therefore to identify difficulties arising that had made escape very difficult and to relate such difficulties to a wide range
of possible vehicle-accident scenarios for assessment purposes. In considering the above, it was recognized that vehicle doors would remain functional in all non-accident circumstances.

### 9.2 THE ROLE OF EMERGENCY LIGHTING

From a consideration of the witness statements and the results of the interviews it was very clear that one of the key factors promoting the desire to escape from the vehicle was the darkness experienced in many accidents. The failure of the lights to survive the impact resulted in passengers being suddenly plunged into darkness without any ability to comprehend what had happened, how serious the situation was, the extent of the damage to their vehicle or the threat to their life. Inevitably, in such a situation, fear of the un-seeable and unknowable is generated, followed by an overwhelming desire to escape the potentially threatening scene. Such an experience has been described as being in a tumble drier in the dark, with the overwhelming desire to escape resulting.

Inevitably, in the absence of any visual information, the situation was always perceived as life-threatening. Research was undertaken into the provision of lighting specifically for such emergencies with the principal requirement that it should be able to survive the impact of a crash. The research explored the various objectives of emergency lighting in relation to rail vehicles. The ‘Stay-or-Go’ research had indicated that, in the aftermath of an accident, the risks to a passenger exiting the vehicle were considerably greater than those to passengers remaining on board until a safe exit was secured. The absence of any lighting would inevitably provoke the immediate desire to “go” and therefore the preservation of lighting was seen as crucial to encouraging passengers to temporarily remain inside the vehicle for their own safety. Since the desire to escape was not related to the need to escape, it was vital to separate them in the perception of passengers in the immediate aftermath of an accident. The preservation of emergency lighting was deemed vital in permitting passengers to identify when a real need to escape existed and when there was no threat. Equally, as indicated below, it was recognized that the use of lighting installations suggesting escape, such as aircraft style floor lighting, were not compatible with encouraging passengers to stay within their vehicle where there was no direct threat to their safety evident.

A literature review was undertaken to establish best practice in buildings and other forms of transport, and the particular requirements in the type of emergencies that could be experienced in the other forms of transport. These were compared with current requirements in rail transport applied in America, Britain and Europe. Workshops were held during which participants with a wide range of specialist expertise (rail and non-rail) sought to establish the key objectives for emergency lighting in rail vehicles, how those objectives could be achieved, what could impede the achievement of those objectives, what levels of lighting would be appropriate to meet the objectives and whether justification existed if meeting those objectives for rail applications resulted in different requirements from those in other forms of transport. Trials were undertaken using the facilities of the HSBC roll-over rig in which a
A rail vehicle was blacked out and various levels of lighting were considered, with and without smoke present. The objective of the exercise was not to evaluate available products, but to evaluate practical levels of lighting and their effectiveness. Earlier research projects (undertaken by RSSB in its previous form of Railway Safety Ltd.) had been undertaken to review the performance of floor-level lighting of the type used in aircraft, light sticks and photo-luminescent materials (materials that absorb light under normal conditions and are self-illuminating in the dark). The exercise provided direct experience of a variety of levels of illumination and permitted an evaluation of the acceptability of each to be made, and its appropriateness to each objective.

With the benefit of such background work, a draft specification for emergency lighting was developed and lighting to meet the draft specification was installed within a representative rail vehicle for validation as indicated in Figure 39.

The lighting level was measured throughout the vehicle at floor level and at table-top level, and the uniformity of the lighting was assessed against the objectives. The unanimous conclusion of the participants was that the lighting level provided was sufficient to permit passengers to interpret the situation, to administer emergency first aid where crucial and to remain on-board for safety. The lighting level was then reduced by switching out alternate lights in order to assess the margin of performance, the effect of uniformity and the potential acceptability of lower levels where it may make retrospective installation more feasible. In the reduced lighting condition the uniformity of lighting was found to be more significant than the precise level of illumination when passengers were walking along the vehicle. The greater the variation in lighting level on the floor of the aisle, the more difficult it was for the eye to keep adjusting to the variations whilst walking along the aisle. The draft performance specification was revised to take account of the optimum levels and uniformity of emergency lighting identified during the testing.

An emergency lighting unit was successfully subjected to two simulated crash tests without any effect on its performance, demonstrating that such equipment was capable of continuing to perform adequately during and after an accident.

The outcome of the research was a specification for emergency lighting that was achievable and survivable in the event of an accident.
9.3 THE USE OF WINDOWS FOR ESCAPE

As indicated above, a significant number of passengers chose to exit through windows after an accident, particularly after the publicity surrounding the Ladbroke Grove accident. The research identified that there was no case discovered in numerous vehicle accidents reviewed, in which the lives of passengers were or could have been prejudiced if windows could not have been used for escape (eg see Appendix L). Exiting through windows was also reviewed.

Exiting through bodyside windows, whilst the rail vehicle remained vertical, was hazardous but not impossible. As can be seen from Figure 40, it represents a sheer drop with nothing to break the fall. Exiting the vehicle in this way renders the passenger vulnerable to the often unpredictable conditions of the ground beneath the vehicle and to any passing trains (where still operating). In some cases vehicles had remained upright after the accident but had been perched perilously in the air – a situation that may not be realised during the hours of darkness. In another recent accident, vehicles have formed a bridge between a steep embankment leaving passengers with a drop of over 4 metres onto a steeply inclined embankment of very slippery mud.

The situation of a vehicle on its side was reviewed by experiment on the industry’s roll-over rig, which permitted a vehicle to be turned over on its side for evaluation and training purposes. In such a situation, exit via a bodyside window would require the use of seat armrests like rungs of a ladder to climb up to the window which must then be broken above the passenger’s head. The situation is illustrated in Figure 41. Striking the window with a hammer from such a position results in a glancing blow, rather than a direct impact, reducing the effective blow to the window. In order to offset this extra force must be applied with the increased risk of overloading the hammer and of the hammer breaking. A successful strike of the window would then result in, or necessitate, the extraction of the glass panel directly above the head of the passenger seeking exit. It is unlikely that the glass would be removed in convenient small sized particles and the safety of the window-breaking passenger could be seriously prejudiced. Where the breaking of the window was successfully
achieved, the passengers would need to lift themselves up through the broken window, using other armrests to gain leverage, and exit onto what would have become the top surface of the overturned vehicle (see figure 42). Passengers would be liable to suffer laceration of their hands, due to jagged fragments of glass inevitably remaining in the window frame, whilst hauling themselves through the broken window aperture.

In front of, and behind, may be further broken windows which, in the dark, would be potential hazards to be negotiated. Even discounting such hazards, descending from such a lofty position, probably in excess of 2.8m above the ground, would be extremely hazardous with a relatively smooth curved roof surface forming one vertical ‘wall’ and the other vertical ‘wall’ comprised of potentially damaged equipment or smooth equipment covers.

Figure 42 Exit from the top side

Hurried exit from a vehicle involved in a rail accident is seldom necessary, fire being the main exception. Exit via windows in the case of fire was considered in relation to the likely scenarios of fire development. The only accident of significance in the UK where fire was involved was that at Ladbroke Grove. It was recognised that exiting a vehicle in the aftermath of a major collision would have involved a number of distinct stages:
1. Time taken for passengers involved in the severe impact at a combined closing speed of approximately 150 mph to realise what had happened and make the decision to escape.
2. Time taken making the decision to get out through a window and to locate a window-breaking hammer.
3. Time taken to get to the hammer location and remove the hammer from its housing.
4. Time identifying an appropriate window which, in the most favourable orientation of the vehicle, may be immediately adjacent to the hammer location.
5. Time to break two separate panes of glass and to clear the glass.
6. Time to exit via the windows that would also be dependent upon the location and condition of the ‘landing’ site adjacent to the vehicle.

Whilst it is often assumed that exit through windows is the quickest means of exit, and whilst these stages could be progressed rapidly in the most favourable conditions, in the event of an accident it is likely that a significant passage of time would occur. Further, in the event of a roll-over, or a partial roll-over, the time taken for all of the steps described above would be extended significantly and the physical condition of passengers would probably have been adversely affected by the impact of the vehicle overturning. It was also recognised that, in the event of only one or two
windows being broken for escape, evacuation of a significant number of people through those windows would take time.

A remote situation where urgent escape may be required would be that of a partially submerged, or submerging, vehicle after derailment. The time taken to pass through the above stages of exit would be crucial in such a case and more rapid escape routes would have greater potential for saving life (see section 9.8).

9.4 HAMMERS AND HAMMERLESS WINDOW BREAKING SYSTEMS

Early research undertaken by RSSB’s predecessor, Railway Safety Ltd., included investigation of window breaking systems in current usage, including hammers and hammerless systems. The research undertaken represented an overview of systems in current usage in the UK. This work indicated that hammerless systems as already trialled in the UK were likely to be more consistent in operation because the successful operation was less dependent upon the passenger operating it. This work did not review the desirability of breaking windows for escape, but was extended by RSSB as indicated below.

In view of reports from a number of accidents indicating that some passengers had been unable to break windows and that, in other cases, the hammer itself had failed, an investigation into hammer specification and performance was undertaken. Whilst at least one hammer design carried an indication that performance was proven for glass up to a thickness of 5mm compared with a glass thickness on rail vehicles of 6mm, this suitability depended equally on the type of glass used. Hammers used on rail vehicles had been subjected to tests in order to verify their suitability. Representatives of the hammer types used in the UK were subjected to a test of their ability to break standard type windows and to perform repeatedly. Hammer breakage occurred in some of the tests and, from those incidents, it was possible to identify the circumstances in which the hammers broke. It was evident that hammers impacting at 90° to the glass were effective but, when impacting the glass with a glancing blow, such as would be the case in an overturned vehicle (see Figure 40), the stress pattern in the hammer change significantly and could result in failure. As a result of numerous tests covering the range of hammers available, it was possible to develop a specification identifying:

- the strength requirements for the hammer (including the case of the oblique angle impact typical of use in an overturned vehicle)
- the tip hardness characteristics for ensuring the point would not be blunted by repeated striking of a glass window
- a test methodology for ensuring compliance with the requirements

In addition to the earlier review and the hammer evaluation research, other types of escape window used in America and Europe were investigated. Test results and videos of operation were examined. It is not possible here to provide a critical performance review of each type of system investigated; however, it was concluded that in all of these cases the type of material used (usually toughened glass) would not have provided any significant degree of containment.
9.5 FIRE AND THE USE OF WINDOWS FOR ESCAPE

The above review was then related to the situation at Ladbroke Grove. In that incident the vehicle most affected by fire was subjected to two distinct phases of fire. Firstly, the rupture and rapid crushing of a fuel tank produced an aerosol-like atomised spray of fuel into the vehicle which then ignited, causing a fire-ball to race through the vehicle within seconds. There was no time to begin the process of exiting via a window or other means. The major fire that finally engulfed the vehicle did not develop for approximately 7-10 minutes, during which time passengers were able to evacuate the vehicle – including via windows. It was recognised that the fire performance of modern UK vehicles is extremely good with materials being subject to strict requirements contained within Railway Group Standards and their predecessors (extending back to the era of British Rail, when the HST vehicles were designed and built in the 1970s). Whole-vehicle fire tests had been carried out on a vehicle which clearly demonstrated that fire initiation and development was very difficult. The length of time taken for the fire to develop at Ladbroke Grove, even with the materials saturated by fuel droplets, was an indication of that performance. In the event of a vehicle overturning and a fire starting in its interior, passengers escaping from windows in the upper side of the vehicle would potentially be trapped above the flames. Flames or toxic fumes would also escape through the broken window posing a threat to those passengers on the top side. In such circumstances escape through the vehicle doors or gangway would usually be quicker except where not available.

Research undertaken by other organisations using computer simulation has investigated the effect of window glass failing and leaving an open aperture in the side of the vehicle. It was concluded that, as a result, oxygen consumed in the fire would be rapidly replenished from outside the vehicle and the fire would continue to be fed with oxygen. There is equally concern that breaking windows for escape would have a similar effect.

9.6 FIRE SCENARIOS WORLD-WIDE

Since the fitting of laminated glass in windows would reduce the possibility of exiting through windows, possible fire scenarios were further considered very carefully. Having considered those cases occurring in the UK and other potential scenarios deemed credible, a review of fires in rail vehicles throughout the world was undertaken to identify other credible scenarios that had not been evaluated. The particular circumstances of each incident were considered to determine whether the same event could happen in the UK and, if so, whether there would have been sufficient time to exit via a window.

A listing of significant accidents and incidents across world railways since 1999 was obtained to identify their causes and their casualty consequences as a preliminary to assessing the probability of such events happening in the UK. The listing is included in Appendix M of this document and those involving fire are extracted below.
• 19 August, 2000 - Kenya: at least 25 were burnt to death after a goods train carrying gas rolled back, smashed into stationary wagons and exploded.
• 11 November 2000 – Kaprun disaster, Austria: A funicular train caught fire in a tunnel; 155 died.
• 20 February 2002 – Al Avatt train disaster, Egypt: A train packed to double capacity caught fire; 373 died.
• 6 November 2002 – Nancy Sleeper car fire, France: A sleeping car caught fire; 12 people died through smoke and toxic fume inhalation.
• 18 February 2003 – Daequ subway fire, South Korea: A mentally ill man started a fire which engulfed two subway trains, killing some 200.
• 18 February 2004 – Nishapur, Iran: A train derailed and caught fire, exploding hours later. About 300 were killed.

Consistent with experience in the UK, there were very few events involving fire – six events involving fire out of a total of 80 events. However, each incident was identified and investigated in order to understand the particular circumstances leading to each and whether those circumstances could occur in the UK mainline railways. The severity of incidents assessed by the number of fatalities alone is no guide to the potential risk in the UK rail environment. The circumstances of each incident and the fire performance of the vehicles are the most significant factors in any comparison as can be seen from the following individual analyses.

In the Kenyan disaster of 19 August, 2000, the accident was between two non-passenger trains and the 25 people killed were burnt to death following explosion of the gas carried in one of the two freight trains. This was not a passenger incident and is not relevant to the considerations in this report. It is worthy of note that such flammable freight is not carried by rail in the UK.

In the Austrian funicular train disaster of 11 November 2000, the funicular train caught fire in a tunnel with the death of 155 passengers. The vehicles were not designed to the same rigorous fire standards as UK vehicles. It is also understood that passenger door release systems and fire protection systems were not fitted. Subsequent reports indicated that inappropriate materials had been used and fire strategies for the train’s operational environment in tunnels were also inadequate. Many of the deaths were caused by people who, having exited the vehicles, fled uphill into the toxic smoke laden tunnel rather than downhill into the fresh-air filled tunnel section. This was not considered comparable to UK systems and operation.

In the Al Avatt, Egypt, train disaster of 20 February 2002, the train was packed to double capacity and caught fire. The cause of the fire was a portable gas cooking stove being used by a passenger. The problem was compounded by there being no passenger communication system on the train that would have permitted the train to be stopped. The driver therefore continued driving the train for many miles unaware of the fire. The fire
therefore rapidly spread and several coaches became involved before the train was finally brought to a halt. This situation is not comparable to the UK. Cooking by passengers is not permitted, gas cooking was phased out many years ago, and all trains have a passenger communication system whereby the train can be halted in an emergency.

In the Nancy Sleeper car fire of 6 November 2002, the vehicles were approximately 60 years old and not to fire standards comparable with modern rolling stock. Because of robberies, the doors were secured from the inside by large metal bolts which prevented access from outside for rescue. There was no central door locking. There was no smoke detection system on-board or means of through communications to the driver. The disaster had many similarities with the Taunton sleeping car fire in the UK which led to significant modifications to the Mark 3 sleeping car vehicles, being designed at the time. These vehicles incorporate a very high standard of fire protection, smoke detection, an alarm system, fire doors, central door locking and through communications. The fire scenario would not be repeated in the UK.

In the Daequ, South Korea, subway fire of 18 February 2003, a mentally ill man started a fire which engulfed two subway trains, the vehicles were believed not to be to the same rigorous fire standards as in the UK and, again, the passenger door release systems were not fitted. This prevented the door locking system from being overridden and preventing escape from the fire. In the UK communication systems would enable contact to be made with the driver, requesting the train to be stopped, and the emergency door release would override the central locking system, permitting the doors to be opened.

From the detailed review of the fire incidents across the world, it was concluded that they had no significance in the consideration of fitting laminated glass for containment for the reasons given above.

Subsequent to the main body of the research work, terrorist activity in India resulted in the fire-bombing of the New Delhi-Lahore 'Friendship Express' in which at least 67 people were killed. The attack, mounted using crude kerosene-based incendiary devices packed into suitcases, set off fires in two of the carriages shortly after midnight local time as the train reached Panipat. The ferocity of the resulting fire resulted in even those escaping from the vehicles being engulfed in flames (Figure 43). The incident resulted in a situation comparable to the initial fireball at Ladbroke Grove, the time taken to escape the vehicle being greater than that required
to evade the rapid spread of fire. In the initial stages of such an incident it is the ignition of the flammable material introduced rather than the ignition of the vehicle interior materials that represents the major hazard. It would be difficult to escape the effects of such a fire in any type of vehicle, although escaping an upright vehicle would be quickest through the doors.

9.7 ESCAPE IN THE EVENT OF EXPLOSION OR OTHER ATTACK

An emerging threat to railways all over the world in the last few years has been that of terrorist attack using incendiary or explosive devices, or chemical and biological weapons.

Consideration of photographic evidence of trains affected by explosive devices clearly indicates that the state of vehicle after the explosion renders the need to escape through windows almost an irrelevance. The damage caused to the metal body shell is usually so extensive as to leave large holes in the vehicle body. These may be used for exit available to those able to exit unaided. In many cases the resulting injuries are sufficiently severe as to require medical treatment on site prior to any endeavour to move the passengers from the vehicles. The train bombings in Mumbai in 2006 were a graphic illustration of the point (Figure 44). The London Underground bombings in July 2005 also illustrated the point. Such events illustrate that there is a practical limit, and sometimes a technological limit, to what can be protected against where groups are determined to nullify all designed-in protection. Nevertheless, the high integrity of modern UK rail vehicles, the high fire performance required and the egress arrangements provided, mitigate the consequences of such an event far as is reasonably practical.

In the case of chemical or biological weapons, such as the sarin gas attack on the Tokyo metro, the object would usually be to cause maximum devastation by release on a crowded train. The rapid rate of spread of such toxins would limit the ability of passengers to escape by any means. In such circumstances, the use of windows in a crowded train would be unlikely to provide a viable option for escape.

9.8 ESCAPE FROM VEHICLES DERAILING INTO WATER

Accidents where vehicles have fallen into deep water have been extremely rare anywhere in the world, but there have been occurrences, including one case on Britain’s railways within the last century. Such an event would
usually be caused by the displacement of a bridge followed by a significant derailment of the vehicle. Escape in such circumstances would be very dependent upon the speed of vehicle entry into the water and whether it remained attached to other vehicles which were not submerging. In any event, it is difficult to conclude that the breakage of windows for escape would be of significant benefit in the light of information available from those incidents that have been experienced. Where the vehicle has partly entered the water, the nearest part of the vehicle to safety is likely to be one end of the vehicle. Exit through a side window in such cases would be likely to plunge the passenger into a torrent of water with fatal consequences.

The case in Britain illustrates the situation. In October 1987, the river Towy had become very swollen, the effect of which was to undermine the foundations of the rail bridge on the line between Llanelli and Craven Arms. Eventually the bridge collapsed but the driver of an approaching train failed to see it in the dark conditions and the leading vehicle plunged into the swollen river. The trailing vehicle was left on the remaining part of the collapsed bridge with its disconnected intermediate end partly submerged in the water (see Figure 45). Passengers were able to escape from the doors at the rear-most end of this vehicle (including the cab door) onto the remains of the bridge and move to safety. Four people died in the incident.

9.9 ESCAPING FROM VEHICLES FITTED WITH LAMINATED GLASS

The question of evacuation or escape from a vehicle fitted with laminated glass, in the event of fire, was carefully considered during the research. As already indicated an extensive analysis of vehicle end states and actual accidents was undertaken.

Whilst the identification of accident scenarios included reasonably foreseeable as well as actual accidents or incidents, it was important to understand any problems with availability of evacuation routes from actual incidents. It was considered that with the level of accident being analysed down to individual vehicles, the conceivable and actual accidents were unlikely to result in vehicles behaving in ways that differed radically from all of the orientations considered in the detailed analysis.

The key issues were seen to be:
Whether alternative escape routes were available other than windows
Whether internal or external doors were incapable of being opened
Whether passengers could not open operable internal or external doors
The time available to use the available means of escape.
Whether lives would have been lost in any of the conceivable or actual scenarios if windows could not have been used for exiting the vehicles.

Evidence was investigated with respect to each of the key issues. As already indicated the escape routes of passengers in the seven major accidents (ie the 52 individual vehicle accidents) featured were examined, together with the stated reasons given by passengers for choosing the routes taken.

The evidence indicated that there was no situation that had arisen in which the use of laminated windows would have precluded escape from a vehicle if laminated glass had been installed throughout. Appendix L indicates the results of research into the availability of escape routes undertaken for the Ufton Nervet accident, which is representative of the similar analysis undertaken in the case of the other accidents.

It was recognised that the operability of internal doors could be a crucial factor in the ability of passengers to escape via other routes. Analysis was undertaken of interior door performance and potential areas of improvement were identified. Whilst in the aftermath of Ladbroke Grove it was considered that bi-parting (two-leaf) doors would be advantageous in the case of an overturned vehicle, investigation of past accidents has suggested that the narrowness of each door leaf made them more susceptible to jamming in the event of structural distortion. A single sliding door with a removable panel (eg such as the panels now fitted to High Speed Trains) was considered to be one optimum solution, although it was recognised that the required action needed to more intuitive, with clearer and more visible instructions. It was also vital that photo-luminescent signs should be in direct light for charging.

9.10 VEHICLES WITHOUT POWER ON A HOT DAY

Concerns have been expressed regarding incidents where crowded trains have been stranded without power in hot weather, possibly in direct sunlight. Modern air conditioned vehicles do not have opening windows to alleviate such situations in which the interior temperature and humidity increase. In an incident at Huntingdon, on 23 June 2005, a unit lost electrical power and was stranded in hot weather. Interior temperatures reportedly rose to a level of approximately 46°C. In a small number of incidents passengers have broken windows in an endeavour to alleviate such conditions. Concern had been expressed that the installation of laminated glass would preclude passengers from breaking the windows in order to alleviate such extremes. Whilst passengers may attempt such action in times of heat stress, it is inappropriate for such actions to be accommodated as part of a strategy. Research into the consequences of extreme conditions was therefore undertaken.

Investigation of the rail industry's accident and incident reporting data was undertaken to identify any incidents in which passengers had fainted or been
taken ill as a consequence of extreme vehicle interior conditions. Scientific data and reports were sought relating to the effects of heat on the human body and the limits of exposure that may be applicable in such an event. Adverse reaction to extreme environments results from physiological and psychological phenomena. The physiological situation arises from the need for the body to release unwanted heat, mainly generated within itself. The ability to do this relies on the ability of the ambient environment to absorb the unwanted heat. Thus increases within the vehicle in the air temperature, air humidity and surface temperatures, reduces the ability of the body to reject this unwanted heat. In the extreme, this leads to a rise in the body’s core temperature and the onset of heat stress problems. Absence of air movement will further exacerbate the condition. The psychological situation arises from anxiety, and stress causes increased heart rate, increased heat generation within the body and constriction of the blood vessels supplying blood to the brain, as a result of muscular tension, potentially leading to faintness.

Many vehicles have ventilation systems of one form or another, but continued operation of the fans is then limited by the capacity of the vehicle battery, deprived of its charging system as a result of the failure, to continue powering lights and other essential services, as well as the ventilation fans. However, the amount of air movement from such a system is unlikely to significantly alleviate the interior conditions in the event of a crowded train becoming isolated on a hot day.

Extensive computer analysis was undertaken with respect to a number of different types of rail vehicle in a variety of ambient temperatures and passenger loading conditions in order to identify the maximum duration within which conditions would remain tolerable. In the event of such circumstances it had previously been the policy to rectify the situation as quickly as possible by getting the train operational again. However, the analysis demonstrated that in such a situation the first priority was to estimate how long it may take to resolve the problem, then to identify how long the interior conditions could remain tolerable and then to decide whether evacuation should be arranged as the first action. The computer analysis enabled a tabulated guidance document to be produced which, for the main vehicle types, indicated the time limit for continued passenger occupancy of a vehicle in a variety of conditions of weather and passenger density. The guidance was given to train operators immediately prior to the summer of 2006. It was considered that, with the issuing of such guidance, the type of incident that occurred at Huntingdon should be preventable and that the ability to open windows to alleviate such conditions would not be so critical in future.

9.11 ACCESS FOR EMERGENCY AND RESCUE SERVICES

In recognition of the concerns that the installation of laminated glass for containment may make rescue more difficult, extensive consultation took place with the fire rescue services. The consultation involved the Fire Officer at the Office of the Deputy Prime Minister, the Moreton-in-Marsh Fire Service College and the paramedic services.
The Fire Officer at the Office of the Deputy Prime Minister was responsible for fire policy across the UK and made it very clear that containment should be treated as the priority. With the fire rescue services aware of the types of window fitted in current rail vehicles, they had the equipment to cope with such vehicles. The approach to major incidents adopted by the fire rescue services was investigated. The fire rescue services made it clear that the time taken to force entry was not significant when compared with the time taken to arrive at the scene of a major incident. The fire rescue services had the health and safety responsibility for an accident site and paramedics were unlikely to commence significant operation until the services arrived. The object of the rescue was to save lives not to endanger them. The services emphasised that access via windows was usually treated as a route of last resort and was mainly used for the removal of stretcher-bound cases where manoeuvrability of the stretcher through a damaged vehicle was difficult.

Consultation with the emergency and rescue services confirmed that laminated glass of the type proposed did not present a problem to their entry to a vehicle in an emergency. Tests were carried out by the Fire Services to verify this. The tests were undertaken using alternative items of equipment, commencing with the most basic equipment to the more specialised, investigating the ease of entry with each.

The various tools used (see Figure 46) included:
(1) A spring-loaded centre punch (for initially breaking toughened glass),
(2) A pry bar (for levering out the glass once broken),
(3) A Glassmaster glass saw (for breaking glass and manually sawing it),
(4) A battery powered reciprocating saw (for powered sawing of glass),
(5) A glass axe (for breaking through glass).

Windows of the type developed were mounted in a position representative of their height when installed in a rail vehicle for the purpose of the test, (see Figure 47). For completeness of the research, the windows were tested in three conditions:
(a) toughened glass on the outside and laminated glass on the inside,
(b) toughened glass on the outside and laminated glass with an anti-spall film on the inside (protecting against small glass fragments separating),
(c) laminated glass on the outside and toughened glass on the inside.

The tests provided further evidence that the laminated glass pane should be on the inside. With toughened glass used on the outside of a double glazed unit, the fire rescue services were able to shatter the glass rapidly with a single blow from a spring-loaded centre punch, allowing the toughened glass
to be cleared very rapidly with a pry bar. This then provided full access to the laminated pane which had to be breached by a glass axe or the ‘axe’ end of the glass saw to create a hole for insertion of the glass saw blade. The laminated glass could then be sawn out. Where the laminated glass was used on the outside of a double glazed unit, the fire rescue services had to breach both panes of glass at the same time in order to be able to commence using the reciprocating saw. This was significantly more difficult and time-consuming and potentially more hazardous for passengers on the inside of the glass as glass dust and fragments from the toughened glass would begin to fall on them. Where both panes were laminated glass, then the difficulty of breaching the outer pane was compounded by the presence of a second difficult pane a short distance behind it. The time was increased further and the production of glass dust increased during sawing through both panes simultaneously. With toughened glass on the outside and laminated to the new specification on the inside, the fire rescue services could gain full access for entry well within two minutes - insignificant when compared with the time to arrive on site.
SECTION 10

A STRATEGY OF CONTAINMENT
10.1 THE NEED FOR A CONSISTENT STRATEGY

Following the Ladbroke Grove accident, Lord Cullen recommended that to avoid confusing passengers in the event of an emergency a uniform set of signage should be adopted across the UK rail network. A uniform set of signage has been developed under RSSB research and is available for use on all rail vehicles. Details of this signage are published on the ATOC website. It is evident that a consistent approach to signage could then be undermined by a fragmented policy regarding emergency escape, in which passenger escape via windows is a recognised escape route in some trains and not in others. Such inconsistency could result in precious time being lost whilst passengers endeavoured to break windows on a train fitted with laminated glass. The adoption of a consistent strategy across the UK rail network is considered to be very important.

10.2 THE PROPOSED STRATEGY

All new vehicles introduced onto the UK rail network since 1994 have been subject to the mandatory requirement that all windows should have one pane of laminated glass for containment except those windows designated for emergency egress. Whilst the research has resulted in the development of a specification for containment, and a laminated window that met it, the question of a consistent strategy relates to whether or not every window should be fitted with a pane of laminated glass to give improved containment of passengers and train crew. The research undertaken has led to the conclusion that the most appropriate strategy is a strategy of containment in which all windows installed on rail vehicles should have laminated glass.

10.3 FITTING TO EXISTING VEHICLES

All vehicles built prior to 1994 had toughened glass windows. The research has established that it would be feasible for a new type of laminated window unit to be fitted as a direct replacement for existing windows during either ad hoc replacement or on major refurbishments.

There are two principal alternative approaches to the fitting of laminated glass windows to existing vehicles. The first would be to modify all windows when vehicles are subjected to a major refurbishment. The second would be to install laminated glass windows whenever a toughened glass window was broken and required renewal.

The implementation of a consistent strategy across the rail network, to avoid confusion, would not require the completion of a campaign change to laminated glass in all windows prior to implementation of the new strategy. However, the fitment of laminated units when an existing window was broken could potentially cause a major conflict with current safety information. In many cases existing signage and safety cards indicate that windows are an option for escape. Removal of all associated signage and deletion of associated instructions on safety cards would facilitate the fitting of laminated glass units in any window location where a toughened unit had been broken.
Similarly, all hammers would need to be removed from the vehicles to avoid the inference that the windows could be broken with such a hammer. Whilst it would be possible to break any remaining toughened glass windows, it would become increasingly difficult to differentiate between remaining toughened units and successively installed laminated units.

Once such a programme was commenced, the benefit in containment would increase with every additional laminated glass window unit installed.

10.4 EXISTING RAILWAY GROUP STANDARDS

Train operating companies (TOCs) can choose to implement the strategy without any change to the current Railway Group Standard GM/RT2456, (Structural requirements for windscreens and windows on railway vehicles). Clause 3.1 states that “Bodyside windows shall provide the maximum possible containment of passengers and train in the event of an accident, except were the window is designated as an emergency egress”. Clause 3.2 adds, “All bodyside windows, except those designated for emergency egress, shall have at least one pane of laminated glass, or other material with similar structural properties, or better….” However, in order to ensure that all future vehicles are fitted with laminated (or equivalent) windows, and to support a consistent approach across all TOCs in future, a change to the Standard to require laminated glass in all new vehicles is going to be proposed and consulted upon.
SECTION 11

A SUMMARY REVIEW OF

WINDOWS AS A MEANS OF ESCAPE
11.1 SUMMARY ON THE USE OF WINDOWS AS A MEANS OF ESCAPE

1. Historically toughened glass windows have been used in rail vehicles. Such windows can be broken for emergency escape purposes.

2. Toughened glass windows have resulted in involuntary exit of passengers becoming a principal cause of fatality in accidents.

3. A strategy based on the breakage of windows for escape is therefore inconsistent with the need to prevent involuntary exit via windows. Where a few windows of toughened glass are provided for escape purposes adjacent passengers are left vulnerable to involuntary exit in the event of an accident.

4. The use of laminated glass at all bodyside window locations would provide resistance against penetration in accidents, when impacted by external objects or ‘airborne’ passengers, but would prevent windows being used as a means of escape.

5. Lives have been lost due directly to the failure of windows. However, in the seven major accidents occurring in the UK during the last 10 years, involving 52 individual vehicle accidents, no case has been found in which a life would have been lost if windows could not have been used for escape.

6. In the case of 51 of the above vehicles, accident data clearly indicates that some passengers escaped from each of the vehicles by means other than windows. Insufficient information is available on the remaining vehicle, although indications are that some passengers exited by means other than windows. It was concluded that all vehicles therefore had routes other than windows available for passengers to escape.

7. Escape through windows is dangerous and exposes the passenger to considerable risks in the process of exiting, which are often increased by the nature of the location to which they are exiting. Examination of accident scenes has indicated that, when the vehicle has derailed, the potential dangers can be considerably increased, especially where the vehicle lies on its side.

8. The time taken to break windows and escape is seldom short. It is dependent upon the device provided for breaking the window, the location of that device, the immediate effectiveness of the device and the orientation of the vehicle from which escape is required. In the case of an overturned vehicle, overhead breakage of the glass is difficult and renders the passengers vulnerable to a considerable mass of glass falling on their heads. Escape from windows can be both dangerous and time-consuming.
9. To avoid uncertainty and confusion in an emergency, a uniform strategy across the whole UK rail industry is essential. This should be a strategy of containment.

10. Adopting a strategy of ‘all laminated glass’ would not require a retrospective campaign to install laminated glass in all vehicles to deliver benefit. It would permit the replacement of toughened glass windows with laminated glass whenever window replacement was required.

11. To permit such ‘as and when’ replacement at any window location and to avoid the risk of passengers wasting precious time trying to break a laminated glass window, it would be necessary to remove hammers from all vehicles and remove window egress instructions from all safety cards and labels.

12. The exclusive use of laminated glass to provide containment is a strategy fully supported by the emergency services and experts in aircraft emergency evacuation.

13. Implementation of such a strategy would not conflict with any current requirements in Railway Group Standards but the strategy would be clearer if, in the first instance, the stated exemption of emergency escape windows from the mandatory requirement to fit laminated glass was deleted to avoid a confused message. However, the supplementary requirements to provide effective containment, as identified in this research, would need to be included in appropriate standards.
SECTION 12

RISK ASSESSMENT SUMMARY
12.1 BACKGROUND

The research pointed towards a strategy of containment based on fitting laminated glass to all windows in a vehicle. If all windows were to be laminated, then the post-accident egress strategy had to be changed. Passengers should be directed away from using the windows. The change process could be broken down into two Actions:

Action 1: Windows are no longer promoted as an egress route, so hammers are removed and signage and notices are changed accordingly.

Action 2: The replacement of toughened glass with laminated glass to all windows within each vehicle.

The risk assessment considered the following scenario. Action 1 was carried out simultaneously across all GB fleets. Action 2 was then considered on a fleet-by-fleet basis. For a given fleet, Action 2 may be carried out a number of years after the implementation of Action 1, or indeed may not be carried out at all.

This would have the advantage of implementing a consistent egress policy across all GB fleets. At present, the policy was inconsistent, with hammers having been removed from some fleets but not others. Moreover, implementation of Action 1 would direct passengers away from the egress method that was most hazardous in most cases, namely climbing through windows.

Another advantage of Action 1 was that it allowed for what may be called ‘ad hoc lamination’ for fleets where Action 2 had not been implemented. Under this circumstance, broken windows would be replaced with laminated examples as and when breakage occurred. Some containment benefit would be gained each time this procedure was followed.

In Action 1, however, the risk assessment was not simply a matter of comparing the large benefits of containment with the small disbenefit of having fewer egress options. Instead, a comparison of the availability of different egress routes and the associated risk was needed, across a wide range of post-accident conditions. Those matters depended on both the physical state of the vehicle and human behaviour.

12.2 OBJECTIVE

The objective of the work reported here was to explore whether or not a risk case could be made for:

- Action 1 on its own.
- Action 1 with ad hoc lamination.
- Action 1 and Action 2*.

* For Action 2, it had been assumed that full lamination was carried out on all fleets. In reality, this may not be the case; as each train operating company would assess the case for full lamination on a fleet-by-fleet basis.
12.3 RISK ASSESSMENT METHODOLOGY

A risk model was developed, informed by inputs from experts in train accidents and human behaviour in emergency situations, via a series of three whole-day workshops. It soon became apparent that it was not possible to develop a fully quantified risk model for all of the benefits and disbenefits, taking into account all the possible human behaviours, due to the lack of available data.

Instead, the modelling explored whether an argument could be made in the following form.

Having completed Action 1 (removed hammers and signage), an operator would have in the large majority of accident scenarios, provided:

EITHER a place of relative safety on the train,  
OR a possible means of egress other than a window,  
AND a transition strategy implemented prior to the introduction of Action 1, for example signage and notices, and public education, which would make it reasonably likely that passengers would stay on the train or use the non-window route.

The methodology focused on identifying the credible accident cases where the passengers did not need to leave the train or – if they did – there was a viable method of egress other than the windows. It also looked at whether the current tendency of passengers to think of windows as the main means of egress could be countered by appropriate mitigation measures included in an industry transition strategy.

Note that there remained cases where the conditions were not met. In those cases, there was a residual increase in the risk, because passengers would have been directed away from windows that would have provided a safety benefit by increasing the number of available egress routes. This increase had been assessed and was compared with the counterbalancing benefit gained by the additional containment from ad hoc lamination and full lamination.

12.4 RISK MODELLING

The need for egress and the availability of egress routes depended strongly on the type of vehicle and on various features of its post-accident conditions. To ensure that consideration had been given to all the relevant combinations of conditions, event tree\(^1\) based models were created, one starting from a collision or derailment, the other from the outbreak of a fire on the train.

\[^1\] Event tree analysis is a structured method of identifying what scenarios might follow an accident, how likely these scenarios were, and what consequences could result from a particular scenario.
For each identified scenario from the event tree, the following questions were considered:

1. Is the current location a place of relative safety (ie, is it safe relative to egress from the train)?

2. Are non-window means of egress reasonably available (such as doors or end gangways)?

3. If there are no non-window means of egress, would windows make a difference to safety outcomes?

4. If passengers should stay, or make use of a non-window egress route, are there reasons why they would not do so (ie, are there 'psychological barriers')?

5. If there are such reasons, what can operators do to make the desired behaviour more likely (mitigation measures)?

At the workshops, a representative sample of conditions was chosen for discussion. On the basis of what was said, rules were developed for extending the answers to all the other conditions.

The key accident scenarios included factors such as:

- Vehicle orientation: 0, 45 degrees\(^2\) and 90 degrees (ie upright, leaning, on its side).

- Structural damage to the train that could prevent external doors or gangways being used.

- Internal doors preventing egress through end doors or gangways.

- Fire development at a 'medium'\(^3\) rate where an egress route (window or non-window) could be used to prevent/limit fatalities.

- Submergence in water, eg where a train falls from a bridge.

The human factors input was relevant mostly to questions 4 and 5. Question 4 did not try to capture all aspects of the behaviour of passengers in different post-accident conditions, but rather the general tendencies of passengers to try to use windows. Question 5 then asked to what extent it might be possible to modify those tendencies and what the industry would need to do to deliver a change in philosophy of 'no egress though train windows'.

---

\(^2\) 45 degrees was used to represent a 'critical angle', somewhere between 15 and 75 degrees. This was described as the worst case where movement along the train was slowest. At this angle, some passengers would be so slow it could be assumed that they were unable to make their way to the door.

\(^3\) The assessment of the effectiveness of egress routes was not considered relevant for 'slow' fires (where passengers could remain on the train safely for 30 minutes or more) or 'fast' fires cases (where fatalities would result within up to 2.5 minutes with no real possibility that windows could be used within this time).
To make the calculation of the residual risk tractable, the psychological and physical questions were decoupled by calculating the residual risk subject to the assumption that the mitigation measures had been successful. In other words, the output was the increase in risk if everyone behaved as desired: stay put if safe, use non-windows evacuation routes if egress is necessary and attempt to use windows only in extremis. This meant that, if operators collectively chose to implement Action 1, they must have a transition strategy in place to inform the public in a way that maximised the likelihood that this assumption was true. It was recognised that an ideal limiting case was being modelled. It was not possible to carry out an analysis of the psychological barriers for all the event tree scenarios. To do so, the modelling would have had to estimate, not only the intrinsic propensity of passengers to want to use windows, but also how this propensity would be modified by the transition strategy and by specific post-accident factors, such as: the presence and type of internal doors, the extent and location of structural damage, the passenger loading of the vehicle, and so on.

Finally, consideration was given to whether windows might provide an escape route for passengers who might otherwise be trapped. It was decided that windows might be effective in the event that the train was upright or at around 45 degrees, but if the train was on its side, evacuation via windows would be so slow and difficult that there would be a negligible benefit.

For the smaller number of cases not ruled out by the filtering rules developed, the focus was back on question 2. Following the workshop discussion, this question was split in two parts.

Q2A Is a non-window means of egress reasonably available for everyone on the vehicle?

Q2B Is a non-window means of egress reasonably available for at least some of the people on the vehicle?

If the answer to the Q2B question was 'no', then the case was called a 'trapping case'. Everyone on the vehicle would be trapped unless they could egress via windows. However if the answer to Q2B was 'yes', it could still be the case that the answer to the Q2A was 'no'. For example, a door may be available in the sense that it was open and people near it could get out, and yet there was insufficient time to get everyone through the door before some were threatened by the fire (those “at the back of the queue” for the door). This was called the ‘hindering’ case.

A simple probabilistic model of egress times as compared with fire development was developed to estimate the increased number of passengers who would be fatally injured should train windows not be available as a means of escape. This model was applied to both the trapping and hindering cases, and was applied for different types of vehicle (end doors, doors at one third and two third points) and for different roll states (upright, 45 degrees, 90 degrees), with different estimates of evacuation rates in each case. One key simplifying assumption made in this model was that it was suitable to
model ‘average’ passengers (ie, no account was made of less physically or psychologically able passengers hindering more able passengers).

This modelling was used to estimate the increased risk due to the unavailability of windows following the implementation of Action 1. As discussed above, this was compared with the decrease in ejection risk as a result of ad hoc lamination. The results were presented in Section 12.5, below.

12.5 RESULTS AND DISCUSSION

The risk assessment concentrated on whether there was the potential for safety disbenefit associated with removal of train windows as an emergency escape route. This enabled comparison with the potential safety benefit arising from the fitment of laminated windows. This in turn allowed an assessment to be made of whether or not there was a case for a change in policy to remove the use of train windows as an escape route from trains, together with either ad hoc lamination of train windows that became damaged during the normal course of events or full lamination of windows on a fleet-by-fleet basis.

This risk assessment only considered the disbenefits associated with the change of policy. Owing to the lack of data and the difficulty in deriving meaningful quantitative risk estimates, it did not quantify the benefits of moving to a consistent policy across all operators and fleets; nor did it quantify the disbenefits associated with using train windows as a means of escape, such as:

- The potential for passengers to jump down through large drops onto uneven surfaces was greater when using windows than when using external train doors.
- When a train has rolled over to an angle, there is the potential for passengers to be hit by falling glass after breaking windows.
- Passengers evacuating via windows may injure themselves on sharp glass.
- If the vehicle had rolled onto its side, climbing out of the window vertically was difficult, and left the person on what was effectively now the roof of the vehicle with difficult drops on either side (as well as the possibility of falling through other broken windows).
- Any potentially life-threatening situation (ie, time-constrained, such as with a fire), where there was a need to escape anything which might discourage passengers from taking the quickest form of egress, should be regarded as a hazard. In some cases, windows would be a much slower alternative to the preferred doors option; thus, egress via the windows could be considered to be a hazard in those cases.

The quantitative element of the risk assessment, therefore, inevitably predicted that there was a safety disbenefit associated with Action 1.
However, this needed to be considered in context of the safety benefits that would result from the next steps beyond Action 1 (ad hoc lamination and full lamination of fleets where this was reasonably practicable). These beneficial next steps could not be introduced without a change in industry policy to move away from the use of train windows as a means of evacuation.

To ensure a balanced view of the potential safety benefits and disbenefits were considered, the main results of both the qualitative and quantitative risk assessment were presented.

12.6 QUALITATIVE ASSESSMENT

Below is a summary of the main strengths and weaknesses associated with each option.

a) Current situation

Main strengths
- Most trains on the network have at least some breakable windows, providing a viable egress route for passengers in some accident cases.

Main weaknesses
- Retaining breakable windows does not reduce the probability of passenger ejection following high-speed accidents involving lateral carriage displacement.
- Passengers have been conditioned by recent accidents and media coverage to think of windows as the first option for egress, even though the doors and/or gangways may be a better egress route in most cases.
- Windows as an egress route present significant risk in their own right in relation to cuts, falling glass, jumping from height, falling through other window openings, electrocution, etc.
- Inconsistent policy applied across current fleets. That is, some fleets have hammers and signs and others do not. This results in a lack of passenger awareness regarding the most appropriate egress strategy.
- Historically, hammers have been used for vandalism.
- Passengers were vulnerable to being struck by objects through train windows.

b) Application of Action 1 on its own

Main strengths
- Consistent egress policy and advice applied across all fleets.
- Passengers were educated / instructed to use the doors and windows as the primary egress routes, which were inherently safer in the majority of cases.
- Hammers were not available for vandalism.
Main weaknesses

- Retaining breakable windows does not reduce the probability of passenger ejection following high-speed accidents involving lateral carriage displacement.

- Need to re-educate passengers to use the external doors and gangways as the primary egress route via an effective transition strategy (this includes consideration of enhanced emergency lighting and changing unintuitive signage, such as doors with removable panels).

- Although not encountered in recent accidents, some accident cases can be identified where passengers could be trapped, given that hammers were not available to break windows.

- Some fleets have internal doors that were ‘trapping’ and could therefore prevent passengers from reaching the external doors and gangways in an accident.

- Passengers were vulnerable to being struck by objects through train windows.

c) Application of Action 1 with ad-hoc lamination and Action 2

Main strengths

- Consistent egress policy and advice applied across all fleets.

- Passengers were educated / instructed to use the doors and windows as the primary egress routes which were inherently safer in the majority of cases.

- Hammers were not available for vandalism.

- Passenger ejection risk and the risk from passengers being struck by objects through train windows are significantly reduced.

Main weaknesses

- Need to re-educate passengers to use the external doors and gangways as the primary egress route via an effective transition strategy (this includes the consideration of enhanced emergency lighting and changing unintuitive signage, such as doors with removable panels).

- Although not encountered in recent accidents, some accident cases can be identified where passengers could be trapped, given that hammers were not available to break windows.

- Some fleets have internal doors that were ‘trapping’ and could therefore prevent passengers reaching the external doors and gangways in an accident.
12.7 QUANTITATIVE ASSESSMENT

a) Action 1 on its own

The safety disbenefit from Action 1, as compared with the current situation, was estimated to be 0.012 fatalities and weighted injuries (FWI) per year across the network, with the disbenefits arising as follows:

1. **Trapping**: removal of exit capability via windows for passengers on board trains who are trapped\(^4\), such that they are unable to exit via vehicle external doors, end gangways, or are trapped by internal doors. The risk disbenefit from this was estimated to be 0.008 FWI per year. To put this into context, the majority of this risk estimate was derived from accident cases that occur, on average, once every 2000 years and result in 16 fatalities (ie, low-frequency but potentially high-consequence events).

2. **Hindering**: removal of exit capability via windows for passengers on board trains who are delayed using vehicle external doors or end gangways through having to queue behind other passengers. The risk disbenefit from this was estimated to be 0.004 FWI per year. To put this into context, the majority of this risk estimate was derived from accident cases that occur, on average, once every 240 years and result in a single fatality (ie, higher-frequency but potentially lower-consequences events).

These disbenefits assumed that the mitigation/transition strategies were implemented successfully – that is, that passengers were minded to use doors and gangways as their primary means of escape after Action 1 is implemented. Without this, the disbenefit could be significantly greater.

This safety disbenefit represented an increase in the annual risk from train accidents (per Version 5 of the RSSB Safety Risk Model) of 0.14% (ie, it is small, but not negligible).

It should be remembered that this was a pessimistic estimate of the safety disbenefit arising from Action 1 because, as described in the introduction to Section 12.5, owing to the lack of data and the difficulty in deriving meaningful quantitative risk estimates, the estimate did not include the potential benefits of moving to a consistent policy across all operators and fleets; nor did it include the disbenefits associated with using train windows as a means of escape.

b) Action 1 plus ad hoc lamination

Ignoring retrofit of laminated windows (Action 2), the risk increase from Action 1 was compared with the benefits of replacing toughened glass windows with

\[^4\] Note trapping is only a disbenefit if there is an immediate threat to passengers from remaining on the train, such as from fire.
laminated glass windows on an ad hoc basis when windows were broken. The data collected show that around 2.5% of train windows were replaced each year. Therefore, the proportion of windows which would be laminated would increase each year to around 23% after ten years. The chart below plots the cumulative benefits and disbenefits of ad hoc lamination and Action 1 with time. It shows that, during the first year, there would be a small net safety disbenefit, but that after two years a net safety benefit would have been realised; this would increase further year-on-year as more windows became laminated.

Chart 1. Cumulative safety impact over ten years of Action 1 plus ad hoc lamination

This risk assessment was in fact pessimistic\(^5\) insofar as estimation of the disbenefits of Action 1, because:

- An upper bound for the probability of trapping had been estimated from the actual vehicle accident data.
- In its treatment of collisions and derailments, the model took no account of passengers being unable to evacuate due to injuries sustained in the primary accident itself.

c) Action 1 and Action 2

This risk increase from Action 1 should also be compared with the benefits in terms of full containment that result from window lamination. It was estimated that, if all train windows were to be laminated (at the completion of Action 2), then the risk reduction would be 0.37 FWI per year – a factor of 32 greater than the risk increase from Action 1.

\(^{5}\) ie the risk assessment overestimated the magnitude of the safety disbenefits
than the estimated risk disbenefit. The balance of risk benefit was therefore clearly on the side of fitting laminated glass and the removal of windows as a means of escape.

If Action 2 were to be implemented fully on top of Action 1 and ad hoc lamination, with Action 2 implemented uniformly over a 15-year period, then the benefits would significantly outweigh the disbenefits, as shown by Chart 2.

Chart 2. Cumulative safety impact over 15 years of Action 1 plus ad hoc lamination plus Action 2

![Chart 2](chart2.png)

It should be noted, however, that this was an idealised case, as it might not be reasonably practicable to retrofit all train fleets with laminated windows. Furthermore, even where retrofit was reasonably practicable, it was likely to take some time to implement. The overall safety benefit from Action 2 was therefore likely to be lower than shown in Chart 2. However, even 50% of the benefit would still represent a significant improvement over the current situation.

12.8 SENSITIVITY ANALYSIS

As with all risk assessment there was some degree of uncertainty associated with the results. In this case, the main areas of uncertainty in the risk model were:

- The probability of trapping actually occurring, given a scenario which could potentially lead to trapping according to the rules developed in this work. As mentioned above, there have been no cases of trapping actually occurring in the vehicle accident data, therefore this probability had been assessed pessimistically. Should a best estimate rather than a pessimistic
estimate of this probability be made, then the annual safety disbenefit from Action 1 would reduce to 0.006 FWI per year.

- The egress and fire development model was rather simple and did involve several assumed values. An uncertainty analysis was carried out. With all 25 of the key assumptions set to their worst-case values\(^6\) the safety disbenefit increased by a factor of three to 0.03 FWI per year, and the cumulative safety impact showed that there would be a negative (increased risk) impact for eight years following Action 1 plus ad hoc lamination, after which the impact would be positive (reduced risk) as shown by Chart 3. Even with these worst case assumptions, the benefits of Action 2 remained much greater than the safety disbenefits of Action 1 as shown by Chart 4.

- It was assumed that terrorist fires might affect more than one vehicle per train, but not that they were particularly set to trap people on one vehicle, ie, by placing two fires on one vehicle. If it were assumed that terrorists did set such fires and their combined fire growth could still be considered to be ‘medium’, then with worst case assumptions it might be possible to obtain a case whereby the safety disbenefit of Action 1 might exceed the benefit of ad hoc lamination over a ten-year period. In reality, the likelihood of this was considered to be very small.

\begin{chart}
\caption{Cumulative safety impact over ten years of Action 1 plus ad hoc lamination with worst case assumptions for the safety disbenefit of Action 1}
\\
\begin{tabular}{|c|c|c|}
\hline
Year & Benefit from ad hoc lamination & Disbenefit from removal of windows as a means of escape & Combined result \\
\hline
0 & 0 & 0 & 0 \\
1 & 0.02 & 0.01 & 0.01 \\
2 & 0.04 & 0.02 & 0.02 \\
3 & 0.06 & 0.03 & 0.03 \\
4 & 0.08 & 0.04 & 0.04 \\
5 & 0.1 & 0.05 & 0.05 \\
6 & 0.12 & 0.06 & 0.06 \\
7 & 0.14 & 0.07 & 0.07 \\
8 & 0.16 & 0.08 & 0.08 \\
9 & 0.18 & 0.09 & 0.09 \\
10 & 0.2 & 0.1 & 0.1 \\
\hline
\end{tabular}
\end{chart}

\(^6\) Worst case was the one which gave the greatest disbenefit for Action 1.
Chart 4. Cumulative safety impact over 15 years of Action 1 plus ad hoc lamination plus Action 2 with worst case assumptions for the safety disbenefit of Action 1

12.9 ‘TRAPPING’ INTERNAL DOORS

One further issue involved trains with internal doors that could lead to trapping should the train roll over. This could occur if one-way sliding internal doors at opposite ends of a vehicle both slid closed in the same direction, as if the vehicle rolled onto its side in the direction that made both doors slide closed, they could trap the passengers between them (the doors were very difficult to open in this situation). Lord Cullen, in the Ladbroke Grove Inquiry Report, recommended that such doors be phased out, either by reversing the direction of slide of one of them, or fitting them with push-through panels. According to the information supplied, and used in the model, there were very few such vehicles with ‘trapping’ doors still in use on the network.

Currently, no vehicles with end external doors and with ‘trapping’ internal doors were in use. On trains with one-third two-third external doors, only 0.15% of passenger miles were affected by ‘trapping’ internal doors. The risk model considered the impact of such doors, and estimated that trains with this type of door had a risk level which was about 70% greater for the key outcomes where evacuation via windows might have a beneficial impact. Whilst it was not considered that this difference was so large that it should delay implementation of Action 1 until the remaining trains with ‘trapping’ doors were modified, it was clear that the remaining modifications would need to be afforded greater priority if Action 1 were implemented.
12.10 TRANSITION STRATEGY

In order to minimise the potential safety disbenefit from the implementation of Action 1, a managed transition to the new industry policy of ‘no egress through train windows’ was required. The industry would need to work together to establish precisely what this strategy should contain and how it would be implemented.

In general the objectives of a transition strategy should be:

- To maximise passenger knowledge in advance of an incident occurring.
- To maximise understanding and hence recall by explaining ‘why’ in advance of an incident occurring.
- To ensure that all the cues and indications in vehicles were seen to match the disseminated desired egress policy.

A key factor in passengers’ decision to egress the train was if they perceived themselves to be under immediate threat. Emergency lighting would help passengers to make more sensible decisions, given the difficult circumstances in which they found themselves. Emergency lighting solutions were available that had been demonstrated to maintain lighting after being subjected to accident conditions.

12.11 RISK ASSESSMENT CONCLUSIONS

This analysis has assessed the potential change in safety risk associated with an industry strategy to remove hammers and signage from trains and encourage the use of the external doors and gangways as the primary egress routes following accident scenarios requiring train vehicle evacuation (Action 1). The analysis has then considered the potential safety benefits to be gained from the replacement of the breakable emergency windows with laminated windows which can help in containing passengers within the vehicle following collision and derailment accidents (Action 2). Two potential replacement strategies have been considered: one involving ad-hoc replacement as windows break in-service and one involving fleet-by-fleet replacement.

The analysis has considered both the qualitative and quantitative changes in risk when compared to the current situation on the network today.

From the analysis it has been concluded that:

1. If Action 1 were applied on its own, it is likely that there would be a small (but not necessarily negligible) safety disbenefit. This disbenefit arises from (a) a few (rare) accident cases where it is possible to trap some passengers within a vehicle with no means of escape if windows were unavailable for use as an escape route, and (b) from some (slightly more frequent) accident cases where a small number of passengers were
hindered in evacuating quickly by the unavailability of windows. The quantified risk increase from Action 1 on its own is small, and if it were possible to consider quantitatively other factors such as the potential benefits of moving to a consistent policy across all operators and fleets and the disbenefits associated with using train windows as a means of escape, the magnitude of the risk increase for Action 1 is likely to be much smaller. These factors have only been considered qualitatively within the analysis.

2. If ad hoc lamination were carried out when train windows need replacing following damage in service, then the safety benefits of this were quantified to exceed the disbenefits associated with Action 1. Initially, however, there could be a disbenefit until sufficient windows have been laminated to balance the risk increase due to Action 1. It is expected that this balance would be reached within two years, but this could be as much as eight years if worst case estimates were used in the risk assessment, although this situation is unlikely.

3. The safety benefits of Action 1 and Action 2 together, which includes full lamination, far exceed the disbenefits associated with Action 1. If, however, it is only reasonably practicable to laminate a proportion of train fleets, then the benefits will be reduced in proportion to the number of trains that were not laminated, until the remaining unlaminated fleets were replaced. The benefits were still likely to exceed the disbenefits of Action 1, even within the first two years, unless lamination is only reasonably practicable for a very small number of fleets.

4. Unless a suitable transition strategy is developed and implemented effectively, then the safety disbenefits associated with Action 1 could be much greater than the quantitative results presented here. This is because any passengers who try to break laminated windows could delay any evacuation using external doors and gangways.

5. There were a number of additional factors that were worthy of consideration as follows:

- So-called ‘trapping internal doors’ exacerbate the risk increase associated with Action 1. The proportion of trains with such doors is very small, and the magnitude of the increased risk is such that it should not delay the implementation of Action 1 in itself. Modification of such doors to provide removable escape panels should be given a high priority if Action 1 is implemented.

- The industry needs to ensure that the signage for use with emergency equipment is intuitive to the user. One example is the removable escape panels provided in some internal doors, which should be given a name that properly reflects their means of operation. Appropriate signage should also be provided.
A key factor in passengers’ decision to egress the train is if they perceive themselves to be under immediate threat. Emergency lighting will help passengers in making more sensible decisions, given the difficult circumstances in which they find themselves. Emergency lighting solutions were available that have been demonstrated to maintain lighting after being subjected to accident conditions.
SECTION 13

IN CONCLUSION
13.1 THE PRINCIPAL FOCUS

The focus of this report has been on summarising the research into reducing the occurrence of involuntary exit from rail vehicles in the event of a derailment or accident. It is evident that involuntary exit, particularly through windows, occurs principally when vehicles jack-knife and/or roll over, with the passenger being subjected to movement across the vehicle, whether involving short or large distances.

Research into window performance directly considers and seeks to protect against the possible consequences of such lateral (sideways) movement of the passenger. It equally seeks to protect against the possible intrusion of objects from outside, through the windows, in the event of a derailment or accident.

The seat belt is designed to restrain in the event of longitudinal movement or additionally, in the case of the lap belt, vertical movement as well. The efficiency of seat belts in restraining passengers against lateral movement or roll-over, as in the case of involuntary exit, is unpredictable. It is not the case they are designed to protect against and, in cars, protection against lateral movement or impact is provided by other devices (usually airbags).

In the event of an accident in almost every case passengers are less at risk remaining within the vehicle than seeking to leave the train. The exception is in the event of fire within the vehicle, in which case escape to an adjacent vehicle presents less of a risk than exiting the train. The installation of laminated glass to contain people during an accident is consistent with this.

13.2 SEAT BELTS

Seat belts will not prevent involuntary exit in the case of passengers adjacent to a breaking window sliding along the ground when the vehicle has overturned. The projection of limbs (mainly) through the adjacent aperture usually causes entrapment of the limb between the vehicle and the ground with the resulting extraction of the person from the vehicle.

Despite the focus being on prevention of involuntary exit, resulting predominantly from lateral movement of the passenger as indicated above, the longitudinal case was the determining factor in the evaluation of seat belts.

The use of the two-point seat belt was seen to increase injuries compared with unrestrained passengers in crashworthy seats. This was directly the result of the pendulum-like motion induced by restraint at the hip position and the resulting neck injuries as the head impacted the seat in front.

The use of three-point (lap and diagonal) seat belts was seen to require the stiffening of the seats to support the additional loading imposed on the seat by the top seat belt anchorage point. Whilst the three-point seat belt reduced
injuries in the case of the restrained person, it increased the injuries of unrestrained passengers to unacceptable levels.

The performance of the seat belts was in both cases compared with that of unrestrained passengers in crashworthy seats. In identical longitudinal collision situations the injury levels of unrestrained passengers in crashworthy seats were well within acceptable limits. Whilst the use of three-point belts reduced these injury levels even further for restrained passengers, the necessary stiffening made matters significantly worse as indicated above.

Seat belts are designed mainly to give protective restraint in longitudinal impacts and are not particularly effective in roll-over or jack-knifing, unless a full body harness is used. Seat belts will not protect against intrusion of objects from outside the vehicle.

Seat belts would also restrain passengers in areas of lost survival space, causing significant increases in injuries and fatalities. Further analysis of six recent accidents concluded that although the installation of seat belts could potentially have saved 11 lives lost through involuntary exit, it would have caused 88 to be lost through restraint in lost survival space.

13.3 LAMINATED GLASS WINDOWS

Windows can be designed to give passenger containment in the event of vehicles jack-knifing or vehicle roll-over.

Windows can also be designed to give protection against the intrusion of objects from outside the vehicle which may occur during derailment and consequent unpredictable movements of the vehicle.

As a result of this work it is now possible to obtain such windows to fit existing vehicles as direct replacement. These windows use laminated glass.

Escape through windows is potentially hazardous. It is not the least hazardous of available escape routes in an accident or emergency.

Laminated glass does not present difficulties to the fire and rescue services. Windows are not normally the preferred route of entry to a vehicle for rescue but, if required, the tools carried in modern appliances permit access through laminated glass to be obtained within a very short time. The time taken for the fire and rescue services to obtain access via laminated glass windows is insignificant in terms of passenger survival time.

The risk of involuntary exit from a rail vehicle has been demonstrated to be several orders of magnitude greater than the risk of being trapped by fire and the installation of laminated glass throughout rail vehicles would provide a considerable safety benefit.
The conclusion reached, taking account of the extensive research, and risk assessment, is that breakable windows should cease to be a recognised method of escape to passengers and that laminated glass should be progressively fitted throughout rail vehicles. In support of this the relevant standards should be changed and a consistent strategy for implementation throughout Great Britain should be adopted to avoid confusion amongst passengers in the event of any future rail accident.

RSSB    July 2007
During the course of the research many sources of information were used including:

- Air industry accident and emergency escape consultants
- East Midlands Emergency Planner (Paramedics)
- Fire and Rescue Training College, Moreton-in-Marsh
- Fire Chief, Office of the Deputy Prime Minister
- Glass and glass window manufacturers and test houses
- Health and Safety Executive
- Human Factors specialists
- Interviews with 26 survivors of the Ufton Nervet rail accident in the UK
- Interviews with persons challenging the railway on related safety issues
- Internet search – related research papers sourced from across the world but not restricted to rail transport
- Marine Industry safety experts
- Media reports and interviews
- Motor industry research organisations
- Orthopaedic specialists of Queens Medical Centre, Nottingham
- Rail accident investigation specialists
- Specialist manufacturers and installers of seat belt restraint systems
- Television reconstructions of various rail accidents
- Train operators
- Train owners
- Vehicle surveys identifying vehicle damage and injury locations
- Witness statements from approximately 800 people involved in UK rail accidents
- Workshops convened to include wide-ranging experts to challenge and give direction to various research aspects
APPENDIX A2  WORKSHOPS HELD

1. Stay-or-Go: Determination of credible accident scenarios – 10 May 2002
2. Roll-over rig demonstration of emergency lighting – 23 October 2003
4. Emergency Lighting workshop (1) – 12 May 2004
5. Emergency Lighting workshop (2) – 9 June 2004
6. Occupant Protection Workshop (two-point lap belt) – 19 May 2005
7. Train windows workshop – 20-21 July 2005
8. Windows risk workshop – 14 February 2006
## APPENDIX B

### TABLE B1  DATA COLLECTED FOR ANALYSIS OF INJURY AND CAUSATION (EXTRACT)

<table>
<thead>
<tr>
<th>REF NO</th>
<th>ONSITEME</th>
<th>AGE</th>
<th>STATUS</th>
<th>CLAS</th>
<th>DESIGNATION</th>
<th>ID</th>
<th>SEAT NO</th>
<th>COMPONENT</th>
<th>POSITION</th>
<th>ORI.C TRAVEL</th>
<th>AREA</th>
<th>TYPE</th>
<th>AIS</th>
<th>CAUSE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 207</td>
<td>Male</td>
<td></td>
<td></td>
<td>Class</td>
<td>Designation</td>
<td>ID</td>
<td>Seat No</td>
<td>Component</td>
<td>Position</td>
<td>Ori. C Travel</td>
<td>Area</td>
<td>Type</td>
<td>AIS</td>
<td>Cause</td>
<td>Comments</td>
</tr>
<tr>
<td>S 207</td>
<td>Male</td>
<td></td>
<td></td>
<td>Class</td>
<td>Designation</td>
<td>ID</td>
<td>Seat No</td>
<td>Component</td>
<td>Position</td>
<td>Ori. C Travel</td>
<td>Area</td>
<td>Type</td>
<td>AIS</td>
<td>Cause</td>
<td>Comments</td>
</tr>
<tr>
<td>S 208</td>
<td>Female</td>
<td></td>
<td></td>
<td>Class</td>
<td>Designation</td>
<td>ID</td>
<td>Seat No</td>
<td>Component</td>
<td>Position</td>
<td>Ori. C Travel</td>
<td>Area</td>
<td>Type</td>
<td>AIS</td>
<td>Cause</td>
<td>Comments</td>
</tr>
</tbody>
</table>

- **Personal Details** – Statement Ref, Gender, Age & Status
- **Vehicle Details** – Class, Designation, ID, Seat No, Configuration, Position & Direction of Travel
- **Injury Details** – Body Region, Type, AIS*, Causation & Comments
- **Treatment Location** – On-site & Hospital
- **Egress Method**

* AIS = Abbreviated Injury Scale
### TABLE B2  SUMMARY OF THE INJURY DATA RECORDED FOR ONE ACCIDENT

<table>
<thead>
<tr>
<th>COACH</th>
<th>TABLE BAY</th>
<th>UNIDIRECTIONAL SEATING</th>
<th>OPEN BAY</th>
<th>STANDING</th>
<th>TOTAL</th>
<th>SEATS</th>
<th>% OCC</th>
<th>% INJ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uninjured</td>
<td>AIS 1-2</td>
<td>AIS 3-5</td>
<td>AIS 6</td>
<td>Uninjured</td>
<td>AIS 1-2</td>
<td>AIS 3-5</td>
<td>AIS 6</td>
</tr>
<tr>
<td></td>
<td>Uninjured</td>
<td>AIS 1-2</td>
<td>AIS 3-5</td>
<td>AIS 6</td>
<td>Uninjured</td>
<td>AIS 1-2</td>
<td>AIS 3-5</td>
<td>AIS 6</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B1</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B2</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>G</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>20</td>
<td>21</td>
<td>38</td>
<td>20</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

#### TABLE BAY

<table>
<thead>
<tr>
<th></th>
<th>Uninjured</th>
<th>AIS 1-2</th>
<th>AIS 3-5</th>
<th>AIS 6</th>
<th>AIS 1-2</th>
<th>AIS 3-5</th>
<th>AIS 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>41</td>
<td>58</td>
<td>102</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### UNIDIRECTIONAL SEATING

<table>
<thead>
<tr>
<th></th>
<th>AIS 3-5</th>
<th>AIS 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

#### OPEN BAY

<table>
<thead>
<tr>
<th></th>
<th>AIS 3-5</th>
<th>AIS 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

#### STANDING

<table>
<thead>
<tr>
<th></th>
<th>AIS 3-5</th>
<th>AIS 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INJURED</th>
<th>Facing</th>
<th>Back</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Face</td>
<td>% Back</td>
<td></td>
</tr>
<tr>
<td>% AIS 1-2</td>
<td>60.3%</td>
<td>50.0%</td>
</tr>
<tr>
<td>% AIS 3-5</td>
<td>61.3%</td>
<td>47.6%</td>
</tr>
<tr>
<td>% AIS 6</td>
<td>100%</td>
<td>95.2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Explanation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>*&quot;Uninjured&quot; means the number of people at that type of location (e.g. Table Bay) who were not injured.</td>
</tr>
<tr>
<td>*&quot;Injured&quot; means the number of people at that type of location (e.g. Table Bay) who were injured.</td>
</tr>
<tr>
<td>*Facing&quot; means the number of people at that type of location facing the direction of travel</td>
</tr>
<tr>
<td>*Back&quot; means the number of people at that type of location with their back to the direction of travel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TOTAL PASSENGERS IDENTIFIED</th>
<th>178</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL UNINJURED</td>
<td>63</td>
</tr>
<tr>
<td>TOTAL INJURED</td>
<td>115</td>
</tr>
</tbody>
</table>
APPENDIX C

FIGURE C1 VEHICLE DIAGRAM SUMMARISING VEHICLE AND INJURY DATA

Notes: Identification of passenger locations, and severity of injuries at those locations, removed
APPENDIX D

FIGURE D1 ILLUSTRATION OF INJURY ANALYSIS FOR UFTON NERVET
APPENDIX E

E1 MATCHING PASSENGER DESCRIPTIONS WITH VEHICLE EVIDENCE

“At first it just went all black. Some other passengers were trying to calm people down in the carriage. We also had a priest in there, he was saying please remain calm. Two guys in my car managed to get the hammers and break out of the top windows [as the carriage was on its side – see Figure E1]. I managed to get out through the door at the back….I guess that 20 to 30 people were trapped in that carriage. Inside the carriage there was glass everywhere…. For some, this kind of thing happens very quickly, but for me it happened very slowly. At first it felt like we were going over a bump, like hitting something. A couple of seconds later the train tilted. You felt something was definitely not right. I heard the noise of the wheels screeching very loud. There was broken glass all over the track. The whole thing tilted to the left side of the tracks. My carriage remained on the tracks but on its side, sliding along.”

“I became aware of someone trying to break the carriage window with one of the train’s emergency hammers, he hammered the glass, he cracked it but didn't break it.” (See Figure E2).

“The next thing we knew the train was on its side. It was rolling over…. as soon as the light went out we were in shock. The noise was terrifying. All you could hear was the banging of the rails and the smashing and screeching of the carriages as they ran along the gravel. There was dirt, and glass smashing. It felt as if we spun over. I could feel bodies going on top of me and being thrown different places. I felt my arm go through the window because the glass wasn't there. I managed to pull my head in but my arm was dragged along. That is why I have lacerations.” “When it happened, it was pitch-black. We couldn't see anything, the lights went out and you could just make silhouettes out of people, fortunately people found some glowsticks from the train.” Mr.[□□] and his friends used the illumination function of their mobile phones. "It was the only light source we had."

Further examples include: “[I was] flung from my seat hitting the roof and being flung around a couple of times” and “I was flung from my seat into the air and thrown forward to the left , hitting the glass partition”
## APPENDIX F

### TABLE F1  SUMMARY OF WHAT HAPPENED TO EACH VEHICLE

<table>
<thead>
<tr>
<th>Accident</th>
<th>Vehicle identification</th>
<th>Vehicle fouling adjacent tracks?</th>
<th>Vehicle rolled?</th>
<th>Final vehicle resting angle¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watford</td>
<td>DTCO</td>
<td>Yes</td>
<td>No</td>
<td>90°</td>
</tr>
<tr>
<td></td>
<td>MSO</td>
<td>Yes</td>
<td>No</td>
<td>80°</td>
</tr>
<tr>
<td></td>
<td>TSO</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>DTSO</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td>Southall</td>
<td>Mk3</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>Yes</td>
<td>Yes</td>
<td>180°</td>
</tr>
<tr>
<td></td>
<td>165</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td>Ladbroke Grove</td>
<td>165</td>
<td>Yes</td>
<td>No</td>
<td>30°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>Yes</td>
<td>No</td>
<td>90°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>Yes</td>
<td>No</td>
<td>35°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>Yes</td>
<td>No</td>
<td>90°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>Yes</td>
<td>No</td>
<td>70°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk3</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>No</td>
<td>No</td>
<td>80°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>90°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>80°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>10°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>10°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td>Hatfield</td>
<td>Mk4</td>
<td>No</td>
<td>No</td>
<td>80°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>90°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>80°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>10°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>10°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td>Great Heck</td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>10°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>30°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>180°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>90°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>15°</td>
</tr>
<tr>
<td></td>
<td>Mk4</td>
<td>Yes</td>
<td>No</td>
<td>360°</td>
</tr>
<tr>
<td></td>
<td>365</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td>Potters Bar</td>
<td>365</td>
<td>No</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>365</td>
<td>Yes</td>
<td>No</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>365</td>
<td>Yes</td>
<td>No</td>
<td>&gt;360°</td>
</tr>
</tbody>
</table>

Notes: 1. “Final vehicle resting angle” - 90° means on its side and 180° means upside down
Building on the “Stay-or-Go” research, credible scenarios were identified and the possible outcomes were anticipated. Identification of the credible scenarios was undertaken by a review of databases in the UK, Europe and across the world. The UK rail industry uses the RSSB Safety Risk Model (SRM) as a basis for safety decision making. The SRM identifies a comprehensive list of hazardous events incorporating actual historic data and estimated probabilities of credible events not yet experienced.

<table>
<thead>
<tr>
<th>Hazard event no.</th>
<th>Hazardous Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HET 1</td>
<td>Collision between two passenger trains (other than in stations)</td>
</tr>
<tr>
<td>HET 2</td>
<td>Collision between a passenger train and non-passenger train</td>
</tr>
<tr>
<td>HET 4</td>
<td>Collision of train with object on line (not resulting in derailment)</td>
</tr>
<tr>
<td>HET 5</td>
<td>Collision with object large enough to cause structural damage to the train (object above buffer height).</td>
</tr>
<tr>
<td>HET 6</td>
<td>Collision between two passenger trains in station (permissive working)</td>
</tr>
<tr>
<td>HET 7</td>
<td>Collision between a passenger train and a non-passenger train in station</td>
</tr>
<tr>
<td>HET 9</td>
<td>Collision with buffer stops</td>
</tr>
<tr>
<td>HET 10</td>
<td>Passenger train collision with road vehicle on level crossings</td>
</tr>
<tr>
<td>HET 12</td>
<td>Derailment of passenger train</td>
</tr>
<tr>
<td>HET 14</td>
<td>Derailment of passenger train in station</td>
</tr>
<tr>
<td>HET 16</td>
<td>Abnormal dynamic forces eg Abnormal deceleration</td>
</tr>
<tr>
<td>HET 17</td>
<td>Fire on passenger train in station</td>
</tr>
<tr>
<td>HET 18</td>
<td>Fire on passenger train</td>
</tr>
<tr>
<td>HET 21</td>
<td>Train crushed by structural collapse or large object</td>
</tr>
<tr>
<td>HET 22</td>
<td>Structural collapse at station</td>
</tr>
<tr>
<td>HET 23</td>
<td>Explosion on passenger train</td>
</tr>
</tbody>
</table>

Table G1 Extract from the Safety Risk Model Hazard Event Listing
It was evident that different scenarios could result in similar outcomes, and these were linked.

European data was not consistent, although a project is now in hand to develop a database of consistent accident data across Europe. For the purposes of the research the data collected for the European funded project SAFETRAIN was considered.

American data was also reviewed from the Federal Railroad Administration Rail Accident Database.
## APPENDIX H

### TABLE H1 VEHICLE END STATES

<table>
<thead>
<tr>
<th>End-States</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>13</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>17</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>19</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>21</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>23</td>
</tr>
<tr>
<td>24</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>26</td>
</tr>
<tr>
<td>27</td>
</tr>
<tr>
<td>28</td>
</tr>
<tr>
<td>29</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>31</td>
</tr>
<tr>
<td>32</td>
</tr>
</tbody>
</table>
### APPENDIX I

#### Table I   TEST PROTOCOL (TWO-POINT BELTS)

<table>
<thead>
<tr>
<th>Test</th>
<th>Configuration</th>
<th>Description</th>
<th>Data acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1: 10RD01</td>
<td>95th 95th 95th 900mm</td>
<td>• 4x95th’s: front 2 belted, 900mm seat spacing</td>
<td>Instrumented: • Window side 95th’s instrumented</td>
</tr>
<tr>
<td>Case 2: 10RD02</td>
<td>50th RS 830mm</td>
<td>To Compare RS and H3 pelvic flexibility: • 50th and RS both belted. • 830mm seat spacing</td>
<td>Instrumented: • Both 50th percentiles • Seat belt tension</td>
</tr>
<tr>
<td>Case 3: 10RD03</td>
<td>50th RS 830mm</td>
<td>• Unbelted 50th and belted RS. • 830mm seat spacing</td>
<td>Instrumented: • All available instrumentation • Seat belt tension</td>
</tr>
<tr>
<td>Case 4: 10RD04</td>
<td>50th RS 830mm</td>
<td>• As Case 3 but with staggered seating positions. • 830mm seat spacing.</td>
<td>Instrumented: • All available instrumentation • Seat belt tension</td>
</tr>
<tr>
<td>Case 5: 10RD05</td>
<td>50th RS 900mm</td>
<td>• Unbelted 50th and belted RS. • 900mm seat spacing</td>
<td>Instrumented: • All available instrumentation • Seat belt tension</td>
</tr>
<tr>
<td>Case 6: 10RD06</td>
<td>95th 95th 830mm</td>
<td>• 2x95th’s – belted and unbelted. • ATDs in line • 830mm seat spacing</td>
<td>Instrumented: • All available instrumentation • Seat belt tension</td>
</tr>
<tr>
<td>Case 7: 10RD07</td>
<td>RS 50th 830mm</td>
<td>• Unbelted RS and belted 50th • ATDs staggered • 830mm seat spacing</td>
<td>Instrumented: • All available instrumentation • Seat belt tension</td>
</tr>
<tr>
<td>Case 8: 10RD08</td>
<td>50th RS 800mm</td>
<td>• Unbelted 50th and belted RS. • ATDs in line • 800mm seat spacing</td>
<td>Instrumented: • All available instrumentation • Seat belt tension</td>
</tr>
</tbody>
</table>
| Case 9: 10RD09 | • Unbelted 50th and belted RS.  
• ATDs in line  
• 752mm seat spacing | Instrumented:  
• All available instrumentation  
• Seat belt tension |
| --- | --- | --- |
| Case 10: 10RD10 | • 2x5th – belted and unbelted.  
• ATDs in line  
• 830mm seat spacing. | Instrumented:  
• All available instrumentation  
• Seat belt tension |
| Case 11: 10RD11 | • 2x5th – belted and unbelted.  
• ATDs in line  
• <830mm seat spacing estimated to pick worst case for restrained 5th percentile | Instrumented:  
• All available instrumentation  
• Seat belt tension |
| Case 12: 10RD12 | • 2x95th – belted and unbelted.  
• ATDs in line  
• 950mm seat spacing estimated to pick worst case for restrained 95th percentile | Instrumented:  
• All available instrumentation  
• Seat belt tension |
<table>
<thead>
<tr>
<th>Test</th>
<th>Configuration</th>
<th>Description</th>
<th>Data acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1:</td>
<td>900mm</td>
<td>• Unmodified seat</td>
<td>Instrumented:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 4x95&lt;sup&gt;th&lt;/sup&gt;s: front 2 restrained, 900mm seat spacing</td>
<td>• Window side 95&lt;sup&gt;th&lt;/sup&gt;s instrumented</td>
</tr>
<tr>
<td>Case 2:</td>
<td>900mm</td>
<td>To Compare effect of strengthening seat</td>
<td>Instrumented:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 95&lt;sup&gt;th&lt;/sup&gt; restrained.</td>
<td>• 95&lt;sup&gt;th&lt;/sup&gt; percentiles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 95&lt;sup&gt;th&lt;/sup&gt; unrestrained</td>
<td>• Seat belt tension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 900mm seat spacing</td>
<td></td>
</tr>
<tr>
<td>Case 3:</td>
<td>830mm</td>
<td>To compare effect of seat pitch.</td>
<td>Instrumented:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Unrestrained 95&lt;sup&gt;th&lt;/sup&gt; and restrained 95&lt;sup&gt;th&lt;/sup&gt;.</td>
<td>• All available instrumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 830mm seat spacing</td>
<td>• Seat belt tension</td>
</tr>
<tr>
<td>Case 4:</td>
<td>830mm</td>
<td>To compare effect of unrestrained passenger loading.</td>
<td>Instrumented:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 95th restrained and 95&lt;sup&gt;th&lt;/sup&gt; unrestrained</td>
<td>• All available instrumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 830mm seat spacing</td>
<td>• Seat belt tension</td>
</tr>
<tr>
<td>Case 5:</td>
<td>830mm</td>
<td>To understand effect of stature</td>
<td>Instrumented:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Unrestrained 5&lt;sup&gt;th&lt;/sup&gt; and restrained 5&lt;sup&gt;th&lt;/sup&gt;.</td>
<td>• All available instrumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 830mm seat spacing</td>
<td>• Seat belt tension</td>
</tr>
<tr>
<td>Case 6:</td>
<td>752mm</td>
<td>To compare seat pitch.</td>
<td>Instrumented:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 2x5&lt;sup&gt;th&lt;/sup&gt;s – restrained and unrestrained.</td>
<td>• All available instrumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ATDs in line</td>
<td>• Seat belt tension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 752mm seat spacing</td>
<td></td>
</tr>
<tr>
<td>Case 7:</td>
<td>830mm</td>
<td>• Unrestrained and restrained 50&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Instrumented:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ATDs in-line</td>
<td>• All available instrumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 830mm seat spacing</td>
<td>• Seat belt tension</td>
</tr>
<tr>
<td>Case 8:</td>
<td>830mm</td>
<td>To compare stature</td>
<td>Instrumented:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Unrestrained 50&lt;sup&gt;th&lt;/sup&gt; and restrained Hill RS.</td>
<td>• All available instrumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ATDs in line</td>
<td>• Seat belt tension</td>
</tr>
</tbody>
</table>
| Case 9: | To compare pitch  
- Unrestrained 50th and restrained HIIIRS.  
- ATDs in line  
- 800mm seat spacing | Instrumented:  
- All available instrumentation  
- Seat belt tension |
|---|---|---|
| Case 10: | Restrained HIIIRS and unrestrained 50th.  
- ATDs in line  
- 752mm seat spacing. | Instrumented:  
- All available instrumentation  
- Seat belt tension |
| Case 11: | To compare seat stiffness and unrestrained occupant impact  
- 2x95th – unrestrained. RS restrained  
- 900mm seat spacing | Instrumented:  
- All available instrumentation  
- Seat belt tension |
| Case 12: | Compare effect of fitting retractor belt  
- 95th and HIIIRS restrained with retractor belt.  
- 900mm seat spacing | Instrumented:  
- All available instrumentation  
- Seat belt tension |
APPENDIX K

K1 PASSENGER EXIT ROUTES FROM VEHICLES IN 7 ACCIDENTS

Figure K1 Percentage of passengers exiting via the principal routes

The database supporting figure K1 above clearly indicates that, with one exception, there were passengers who escaped from every vehicle via routes other than windows. The one exception was the leading vehicle at Watford, for which detailed information was not available to confirm the escape routes. Examination of photographic records, however, suggested that escape via routes other than windows had been a realistic option.

A detailed break-down of the exit routes for the Ufton Nervet accident is indicated in Table K1, together with the final orientation of the vehicle from which the passengers exited.
## Table K1  PASSENGER EXIT ROUTES AT UFTON NERVET

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Vehicle end position</th>
<th>People exiting vehicle</th>
<th>Exit via windows</th>
<th>Exit via doors</th>
<th>Exit via gangway</th>
<th>Exit via hole</th>
<th>Not known</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>23</td>
<td>19</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>B1</td>
<td></td>
<td>28</td>
<td>3</td>
<td>12</td>
<td>11</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>B2</td>
<td></td>
<td>36</td>
<td>0</td>
<td>12</td>
<td>21</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>49</td>
<td>27</td>
<td>3</td>
<td>15</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td>27</td>
<td>2</td>
<td>1</td>
<td>22</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>13</td>
<td>1</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>192</strong></td>
<td><strong>53</strong></td>
<td><strong>46</strong></td>
<td><strong>77</strong></td>
<td><strong>2</strong></td>
<td><strong>14</strong></td>
</tr>
<tr>
<td>%</td>
<td></td>
<td><strong>100</strong></td>
<td><strong>27.6</strong></td>
<td><strong>24</strong></td>
<td><strong>40.1</strong></td>
<td><strong>1</strong></td>
<td><strong>7.3</strong></td>
</tr>
</tbody>
</table>

**Note:** Coach end positions indicated as viewed from the rear of the train
Numbers subject to final confirmation following in-depth review
Examples of witness statements describing exit routes chosen and reasons for that choice.

Vehicle A

“The train manager came into the carriage said there had been a derailment and to go with him. By that time someone had smashed a window behind us. We could smell diesel fumes, very strong….We got out through the smashed window which was very close to the ballast.”

Vehicle D

“I could smell a strong fuel and I was fearful of an explosion. The guy who had been opposite me had already got out through a broken window above….I decided to follow him…. The same guy reached down and helped me out. I found myself on what was now the top of the train. I wanted to jump but the man told me not to jump as we did not know what was below. Then a man turned up with a glow stick and said it was OK to jump…. I jumped and the man who helped me out caught me. He then told me to run because of the fuel and risk of an explosion.”

Vehicle E

“I tried to break a window [with hammer] but the hammer broke… I saw another hammer and further lightsticks. I again attempted to break a window but again the hammer broke. ….noticed some light through the sliding doors…. I went to the sliding doors and forced them both open.”
## APPENDIX L

### TABLE L1  AVAILABILITY OF EXIT ROUTES FOR INDIVIDUAL UFTON NERVET VEHICLES

<table>
<thead>
<tr>
<th>Leading Gangway</th>
<th>Trailing Gangway</th>
<th>Saloon aisle</th>
<th>Vehicle orientation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>open</td>
<td>open</td>
<td>open</td>
<td>45 degrees</td>
</tr>
<tr>
<td>B1</td>
<td>open</td>
<td>open</td>
<td>open</td>
<td>upright</td>
</tr>
<tr>
<td>B2</td>
<td>open</td>
<td>open</td>
<td>open</td>
<td>small lean</td>
</tr>
<tr>
<td>D</td>
<td>open</td>
<td>open</td>
<td>possible distortion</td>
<td>small lean</td>
</tr>
<tr>
<td>E</td>
<td>open</td>
<td>open</td>
<td>open</td>
<td>on side</td>
</tr>
<tr>
<td>F</td>
<td>open</td>
<td>open</td>
<td>blocked</td>
<td>upright</td>
</tr>
<tr>
<td>G</td>
<td>open</td>
<td>open</td>
<td>open</td>
<td>small lean</td>
</tr>
<tr>
<td>H</td>
<td>open</td>
<td>open</td>
<td>open</td>
<td>on side</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Passengers exiting</td>
<td>Windows for exit</td>
<td>Hammers used</td>
<td>Gangways available</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------</td>
<td>------------------</td>
<td>--------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>A</td>
<td>23</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>B1</td>
<td>28</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>B2</td>
<td>36</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>49</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>27</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>11</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>G</td>
<td>13</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>H</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>170</td>
<td>11</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

Notes: All vehicle diagrams are indicated as seen from the rear of the train. 23 windows failed, passengers broke 12 (some insufficiently). 55 passengers escaped through windows. 25 light sticks used. Numbers subject to final confirmation following in-depth review.
APPENDIX M

SIGNIFICANT WORLD-WIDE RAIL ACCIDENTS AND INCIDENTS

1999

- March 15 1999  Bourbonnais train accident, Bourbonnais, Illinois, United States: A southbound Amtrak passenger train out of Chicago, Illinois, hits a loaded semi truck at a grade crossing and derails; the accident results in 11 fatalities and over 100 injuries.
- August 2 1999  Two express trains collide head-on in Guwahati, India. Over 285 people are killed.
- August 18 1999  Zanthus train collision, Australia: An engineman incorrectly throws a turnout turning the through train into a collision with a looped train.
- October 5 1999  Ladbroke Grove (Paddington) rail disaster, United Kingdom: Two trains collide head-on, killing 31 and injuring 400.
- December 3 1999  Glenbrook train disaster, New South Wales, Australia: Stop and Proceed rule at red signal applied with insufficient care (too much speed), killing 7.
- 1999 - 32 died at Tsavo National park when brakes on a passenger train failed forcing it to jump the rails.

2000

- January 4 2000  Åsta in Åmot, Norway: Two passenger trains collide on Rørosbanen killing 19 people.
- February 6 2000  Brühl, Germany: A night express train speeds in a construction area and derails at Brühl station, 9 die.
- March 2000  Tokyo train disaster, Japan: A Tokyo subway train derails and is hit by another train on the next track; four are killed and 33 are injured.
- April 5 2000  Lillestrøm in Skedsmo, Norway: A freight train loses its brakes between Strømmen and Lillestrøm and collides with another freight train standing still at Lillestrøm Station. Two gas wagons loaded with propane catch fire and 2000 people are evacuated in fear of a BLEVE, but there are no casualties.
- 15 August, 2000 - 13 died near Kenya's fourth largest city, Kisumu after a passenger train rolled back due to failed brakes.
- 19 August, 2000 - at least 25 were burnt to death after a goods train carrying gas rolled back, smashed into stationary wagons and exploded.
- October 17 2000  Hatfield rail crash, United Kingdom: Part of a rail shatters as a passenger train passes over it; four people are killed, 70 are injured.
- November 11 2000  Kaprun disaster, Austria: A funicular train catches fire in a tunnel, 155 die.
2001

- February 28 2001  Selby rail crash, Selby, North Yorkshire, England: A driver on England's M62 motorway falls asleep at the wheel; his car leaves the road just before a bridge over the tracks, driver escapes, but car is almost instantly hit by a passenger train as the car reaches the tracks, which then hits a coal train in the opposite direction. 10 people are killed, over 80 are injured.
- March 27, 2001  Pécrot rail crash, Pécrot Belgium: Two passenger trains collide on the same track, killing 8 and injuring 12.
- April 12 2001  Stewiacke, Nova Scotia (south of Truro): A teenager tampered with a switch several minutes before VIA Rail Canada's Ocean passed through the town. The resulting derailment destroyed several buildings and passenger rail cars. Many people were injured, several severely although there were no fatalities.
- November 15 2001  Andersonville, Michigan (northwest of Detroit), United States: Two Canadian National Railway trains collide head-on.
- December 23 2001  Rochester, New York, United States: An incorrect brake application on a CSX local train that had stopped to perform switching at Kodak Park causes the train to run away and derail five miles later, destroying homes and businesses in the area.

2002

- January 18 2002  Minot, North Dakota, United States: A Canadian Pacific Railway train derails at 1.40 am C.S.T. near a residential area west of Minot; the derailment results in a massive anhydrous ammonia leak. Seven of 15 tank cars rupture, releasing 200,000+ gallons of anhydrous ammonia which vaporizes in the sub-zero air, forming a toxic cloud that drifts over much of Minot. One man dies and numerous others are treated for chemical exposure.
- February 20 2002  Al Ayatt train disaster, Egypt: A train packed to double capacity catches fire, 373 die.
- May 2 2002  Firmdale, Manitoba, Canada: An eastbound Canadian National train collides with a trailer; about 20 cars carrying plastic pellets, benzene, glycol and hexane catch fire, forcing the evacuation of nearly 200 local residents.
- May 25 2002  Tenga, Mozambique: In an accident eerily reminiscent of Armagh 1889, passenger carriages, separated from a train also carrying freight, run away and smash into a cement train, killing 200.
- June 24 2002  Igandu train disaster, Tanzania: Nearly 300 are killed when a passenger train rolls backwards into a goods train.
2003

- **January 31 2003** Waterfall train disaster, Waterfall, New South Wales, Australia: A train derails as it rounds a sharp curve at too high a speed. It is possible that the driver had a heart attack.
- **February 18 2003** Daegu subway fire, South Korea: A mentally ill man starts a fire which engulfed two subway trains, killing some 200.
- **March 1 2003** Chiayi, Taiwan: A brake system malfunction aboard a train on the Alishan Forest Railway caused the train to lose control and plummet into a valley. 17 were killed and 173 were injured.
- **March 20 2003** Roermond, Netherlands: A Nederlandse Spoorwegen (NS) passenger train collides head-on with a freight train; the NS driver was killed and 6 passengers were seriously injured.
- **June 20 2003** “southern California, United States: A runaway Union Pacific freight train carrying lumber derails in the Los Angeles suburb of Commerce, California, destroying several homes and rupturing natural gas lines.
- **August 3 2003**, Romney, Hythe and Dymchurch Railway, The volunteer train driver, 31-year-old Kevin Crouch, died when his train hit a car on a level crossing. The car driver, a woman with a baby, had apparently ignored or failed to see the crossing's warning lights, and was later arrested on suspicion of causing death by dangerous driving, but was found guilty only on a lesser charge of careless driving. Some of the train passengers were treated for shock and minor injuries.

2004

- **February 18 2004** Nishapur, Iran: A train derails and catches fire, exploding hours later. About 300 are killed.
- **March 11 2004** Madrid train bombings, Spain: A series of coordinated terrorist bombings against the commuter train system, which killed 191 people and wounded 1,460.
- **April 22 2004** Ryongchon disaster, North Korea: Over 50 are killed and more than 1000 injured when an explosion takes place.
- **October 23 2004** Niigata Prefecture, Japan: A Joetsu Shinkansen train derails due to the Chuetsu Earthquake. It is the first time a Shinkansen derails while in service.
- **September 10 2004** Nosaby, Blekinge, Sweden: A heavy truck brakes too late, goes through the gates and stops on the track, and the driver leaves his cab. Two was killed and 47 injured in the crash.
- **November 3 2004** Washington, DC, United States: One subway train lost its brakes and rolled backwards into the Woodley Park-Zoo Station, slamming into another train. Twenty people were injured in the crash.
- **November 6 2004** Ufton Nervet rail crash, United Kingdom: A High Speed Train hits a stationary car on a level crossing (an apparent suicide) at 100mph and derails. Five train passengers and the drivers of both the train and the car are killed; over 100 passengers are injured.
• **November 15 2004** Bundaberg Tilt Train Derailment, Berajondo (near Bundaberg), Queensland, Australia: The world's fastest narrow-gauge train derailed at 108km/h. Remarkably, no-one was killed or permanently injured. The cause of the accident is still unknown and an investigation is still under way.

• **December 26 2004** "Queen of the Sea" train disaster, Telwatta, Sri Lanka: Approximately 1700 are killed in the world's worst rail disaster to date as a train is overwhelmed by a tsunami created by the 2004 Indian Ocean earthquake.

2005

• **January 6 2005** Graniteville train disaster, South Carolina, United States: Still under investigation by the NTSB; preliminary findings are that a turnout is left lined for a siding when it should have been lined for the mainline, causing a through Norfolk Southern freight train to collide with a parked train. Nine killed, the engine crew, and nearby citizens who are caught in toxic gas cloud released from a damaged tank car.

• **January 12 2005** Fort St. John, Manitoba (a suburb of Winnipeg), Canada: Five cars of a CN freight train derail; as one of the cars was carrying propane, the area is evacuated. The tank car remains upright and intact, so local residents are allowed to return fairly quickly.

• **January 17 2005** Bangkok, Thailand: Two metro trains on the near-new Blue line collide. About 140 passengers injured.

• **January 26 2005** Glendale train crash, California, United States: In what was originally thought to be a failed suicide attempt by an automobile driver, a southbound Metrolink double deck commuter train collides with a vehicle that had been driven onto the tracks and derails; the derailed train strikes the northbound Metrolink train on the other mainline track and a parked Union Pacific Railroad freight train on a siding. 11 people are killed, about 100 injured.

• **April 14 2005** Solon Springs, Wisconsin, United States: Nineteen cars of a southbound Union Pacific train operating on Canadian National Railway south of Superior, Wisconsin, derail and cause a forest fire near the town of Solon Springs, Wisconsin.

• **April 21 2005** Vadodara rail collision, India: collision between freight and passenger express train “ 18 killed.

• **April 25 2005** Amagasaki rail crash, Amagasaki, Hyogo, Japan: A train derailed on sharp curve smashes into an apartment building. 107 were killed and 549 were injured.

• **April 26 2005** Polghahawela level crossing collision, Sri Lanka: a bus tries to beat the train at a level crossing; at least 35 people are killed, all on the bus.

• **May 3 2005** Galt (about 50 miles / 80 km east of the Quad Cities), Illinois, United States: Union Pacific Railroad's transcontinental mainline is blocked when a train derails and destroys the 140 ft (43 m) bridge across Elkhorn Creek.

• **May 9, 2005** Biaora level crossing accident, Biaora, India: Eight people die when a bullock-cart is struck by a train at a grade crossing.
• May 10 2005  Houston, Texas, United States: A METRORail train strikes and kills a pedestrian. This is the first fatality accident in the history of METRORail, but overall the 88th crash in the (at that time) 19 month history of the METRORail, which has earned the system nicknames such as "The Streetcar Named Disaster" and "Wham-Bam- Tram". (The 88th crash is the count per official news media reports. However, ActionAmerica.org, a METRORail opposition website, claims that the Houston Chronicle and other local media outlets have purposely failed to report crashes involving METRORail as a means of "conniving" Houstonians to support expansion of the system. ActionAmerica.org believes the total count through the fatal crash may have been higher.)

• May 19, 2005  Lampung, Indonesia: A fully loaded passenger train crashes into a parked freight train at a station.

• June 12 2005  between Uzunovo and Bogatishchevo, Russia (about 153 km / 95 miles from Moscow): At 0710 local time a bomb explodes derailing the locomotive and first four passenger cars of the Grozny-Moscow train. Investigators found wires leading from the explosion site to a control panel and hideout about 50 m (164 ft) from the site.

• June 16 2005  between Zubtsov and Aristovo, Russia on a single-track section of the Rzhev-Shakhovskaya line about 200 kilometers (125 miles) northwest of Moscow: 26 of 69 tank cars derail at a speed of 70 kilometers/hour sending a very large amount of their heavy fuel oil cargo into the ground and contaminating Moscow's water supply and the Volga River after flowing down the Vazuza River from the accident site. About 641 meters of damaged track are subsequently replaced. It is not yet known if this incident is related to the bomb that was exploded on June 12, 2005 that derailed a passenger train.

• June 21 2005  Revadim, Israel: A southbound passenger train collides with a coal delivery truck near Revadim, about 25 miles south of Tel Aviv; the train was bound for Beersheba when the accident occurred. At least seven people die in the accident and more than 200 are injured.


• July 10 2005 Romney, Hythe and Dymchurch Railway, Kent. A 15" gauge steam train collides with a car on a level crossing, killing the volunteer driver of the train. None of the passengers in the train are seriously injured.

• July 13 2005  Ghotki rail crash, Ghotki, Pakistan: A chain reaction accident caused by one train missing a signal and colliding into another results in three trains crashed and over 150 people dead.

• July 31 2005  Shenyang, China: Northbound train K127 from Xi'an to Changchun passes a sabotaged railway signal and collides with a freight train, killing five of the passenger train's passengers. Officials state that some wiring was stolen from a nearby signal box causing the signal to malfunction.

• August 1 2005  Kilkis, northern Greece: A truck driver is killed after he ignored grade crossing warning signs and his truck is hit by an oncoming passenger train of the Hellenic Railways Organization. The
train's crew are only slightly injured, and all of the train's passengers are uninjured and continue their journey by bus.

- **August 2 2005** Raleigh, North Carolina, United States: A dump truck drives around the gates at a grade crossing and is struck by Amtrak's northbound Carolinian passenger train. Both occupants of the dump truck died at the scene, 15 of the train's occupants suffered minor injuries, and the remaining 182 passengers are bussed to another train to continue their journey to New York City.

- **August 3 2005** Wabamun, Alberta, Canada: 43 cars (nearly all of them tank cars) of a 140-car westbound Canadian National Railway (CN) train from Edmonton to Vancouver derail, sending nearly 700,000 litres of fuel oil into Wabamun Lake, and the small creeks feeding into lake Wabamun. Initially, local residents are evacuated as at least one of the derailed tank cars carried toluene, but that tank remains intact. Belatedly, residents are warned to stop using water from the lake and to wear protective gear while rescuing oil-coated wildlife because one of the ruptured tanks is later revealed to have contained pole oil, which is a carcinogen used to treat utility poles. No human injuries are reported, however statistics showed that only one in six birds survived, as well, many other muskrats, beavers, and small animals were covered too heavily in the oil to survive. The accident closed CN's mainline for 36 hours while crews clean up the spill, and angry cabin owners protested by "camping out" on the tracks, forcing all trains to come to a halt. The closure also impacted VIA Rail Canada's passenger trains, requiring passengers to be bussed around the accident scene.

- **August 16 2005** Swanscombe, Kent, England: One maintenance of way employee on the Channel Tunnel Rail Link dies and a second is treated for severe burns when a fire erupts at a railway tunnel construction site. About 50 firefighters responded to the blaze around 7:15 PM local time. Initial reports indicate the cause of the fire may be a collision between two work trains. Regular Eurostar service between England and France is unaffected by the incident.

- **September 17 2005** A Metro commuter train traveling into Chicago derails, killing two and injuring 83.

- **September 18 2005** Rillington, North Yorkshire, England: A 92 year old man dies when he drives his car into the path of a train at a level crossing.

- **September 23 2005** Two CSX freight trains collide outside Franklin, Virginia injuring six crewmen. The crash shutdown part of Route 621 and dumped about 1,000 gallons fuel.

- **September 29 2005** The Amtrak Acela train plowed into a car crossing in Waterford, CT, killing a woman and her 8-year-old grandson and causing delays along the Northeast Corridor.

- **October 3 2005** Madhya Pradesh, India: 16 die when a train travels at 6 times the speed limit and de-rails.

- **October 26 2005** A Merseyrail commuter train derails between Liverpool's Central and Lime Street stations in the evening rushhour.
October 29 2005  Veligonda, South India: At least 89 are killed and many more are injured when part of the track is swept away by a flood and the train de-rails.

26 November 2005  Moy near Inverness, Scotland. Nine people are airlifted to hospital when a First ScotRail British Rail Class 170 DMU derails after hitting debris from a landslide.

November 26 2005  Seattle, Washington: The city's red and blue monorails sideswipe one another at a "pinch point" in the track layout near Seattle Center. None of the 84 passengers is injured.

December 8 2005  27 cars of a BNSF coal train derail at Clarendon, Texas, blocking the single main line track.

December 9 2005  38 cars of a BNSF grain train derail at Mulhall, Oklahoma, blocking the single main line track.

December 26 2005  Yamagata Prefecture, Japan: All 6 cars of an express train derail 180 miles north of Tokyo; 5 people are killed and more than 30 are injured. Strong winter winds are thought to be the cause.

2006

January 23 2006  Bioče train disaster: A passenger train crashes into a ravine near Podgorica, Serbia and Montenegro killing 46 and injuring 198.

January 29 2006  A broken rail causes a derailment near Jhelum in the Punjab, killing 2 and injuring 29. Poor maintenance is being officially blamed, but sabotage is still suspected by some authorities. The government inquiry still continues.

February 5 2006  Thirteen cars on a CSX freight derail just east of Martinsburg, West Virginia, United States, blocking the former Baltimore & Ohio double track mainline for a day.

February 16 2006  Serres, Greece: An inter-city train strikes a truck at a grade crossing near Serres and derails. A passenger and the truck driver are killed, and twenty others on board the train are injured.
Rail Safety and Standards Board Registered Office
Evergreen House, 160 Euston Road, London, NW1 2DX.
Registered in England and Wales No. 04655675.

Rail Safety and Standards Board is a not-for-profit company limited by
guarantee.