Abstract

Fire detection system and firefighting solutions are getting a common safety measure on newly designed and built trains in Europe and other parts of the world. While international and national regulations as laws or the European TSI often prescribe the minimum requirements on vehicle safety, these regulations do not give any guideline to evaluate the performance of such systems.

Thus these regulations describe the necessity of installing a system, but do not introduce a test scheme to measure the system performance. Installation guidelines as known from the building practice do not exist for this field of application. To compensate for this lack of guidelines and standards the European manufacturers of fire safety system for rolling stock together with the attestation and certification bodies have developed a series of guidelines (so-called ARGE guidelines) to determine the system performance and give success criteria for fire detection, aerosol and gas fire extinguishing and water mist firefighting on railway vehicles.

The paper will present the three ARGE Guidelines [1-3] which were developed since 2009 and focus on the experience gained in using these guidelines. The testing methods will be described and the choice of these methods justified.

Keywords: Fire detection, fire suppression, railway vehicles, ARGE guidelines

Introduction

The European Technical Specifications for Interoperability for Railway Traffic (TSI) [1], and the European standard EN 45545-6: 2013 include requirements for the installation of fire detection and firefighting systems. These requirements are depending on the type of vehicle and its class of operation.
However, an assessment of these fire safety systems is not defined in these standards. The ARGE Guidelines Parts 1 to 3 [2, 3, 4] define a practical assessment method based on the objective of personal safety. The same targets have the Italian standard UNI 11565:2015 and the future European standard on “Fire Containment and Control Systems” for railway vehicles in preparation by CEN/TC 256.

**ARGE Requirements on fire detection**

The ARGE Guideline Part 1 “Fire Detection in Rolling Stock” [1] gives guideline to the choice of detector type and defines functional testing of installed fire detection systems on railway vehicles with the target to measure detection response on optimize the detector positioning in the vehicle. It addresses both occupied areas as well as technical areas. The defined target values on thresholds are chosen in order to establish personal safety in the railway vehicle. Testing (here type testing) shall always done on a real vehicle.

*Detection principle*

The ARGE Guideline generally considers both smoke and heat detection. It defines the following choice:

- Potentially occupied areas: smoke detection
- Technical areas: smoke or heat detection

Potentially occupied areas are considered areas in which passengers or train personal can stay, examples are passenger areas, compartments, staff compartments, restrooms, driver’s cabins, restaurants etc. Here usually point-type smoke detectors (EN 54-7) or aspiration smoke detectors (EN 54-20) are in use.

Technical areas are electric cabinets in the passenger area, technical compartments on the roof or under the vehicle, engine compartments etc. The use of fire detectors tested according to EN 54 is stipulated.

*Thresholds*

The following thresholds for the maximum detection times are defined.

<table>
<thead>
<tr>
<th>Area</th>
<th>Maximum detection time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potentially occupied areas</td>
<td>1 minute</td>
</tr>
<tr>
<td>Technical areas (not engines)</td>
<td>2 minutes</td>
</tr>
<tr>
<td>Combustion engines</td>
<td>1 minute</td>
</tr>
</tbody>
</table>

These times are bases on the test assessment described below and include the time of alarm transmission. That means that the time between start of the test and the alarm signal is assessed.

*Testing equipment and assessment*

Testing of smoke detectors is done using a smoke generator with thermal lift. Figure 1 shows the potential test set-up.
The thermal lift is generated using chimney of 50 cm height and
- Either a methanol pan with: 22 cm x 22 cm surface max.
- Or a gas burner with 2.9 W power

The gas burner method was added later to the standard as the methanol creates a risk especially in case of moving vehicles. In case a compartment or technical cabinet is tested in which the chimney does not fit, the smoke generator will be placed outside the cabinet and the smoke lead through a tube with a tubular smoke heater for creating thermal lift (see Fig. 2).

The smoke generator has to be calibrated before the test and following types of fluid are recommended by tests:
- Regular Fog (Look Solutions)
- Base XL (HazeBase)
The quantity of fluid to be used in the test is defined as:

The positioning of the test equipment and the realization of the test smoke's thermal lift should be focused at areas which
   a) are most unfavorable for quick detection of the fire,
   b) permit hidden ignition,
   c) can be used for storage of larger items of travel luggage.

The tests have to be performed with all possible air circulation situations in service (e.g. ventilation ON, OFF, heating, cooling). Thereby individual tests can be omitted if the related situations are covered by other similar air circulation situations. Tests in technical areas have to be carried out at maximum ventilation and without ventilation. For vehicles with windows that can be opened, this means that tests have to be carried out during a test ride as well. As heat release tests cannot be carried out without damaging a prototype, it is prescribed that heat detectors in technical areas have either to be installed in a distance of maximum 0.5 m to any ignition source or a CFD simulation has to prove the position. For heat detection often linear heat detectors are used.

**Justification**
The smoke release rates above where experimentally determined based on the test fires:
- Burning travelling bag ignited by an UIC paper cushion (for passenger areas)
- Cables with thermal overload (for technical areas)

The traveling bag is in alignment with the “ignition model No. 5” of Appendix 1 of EN 45545-1:2013. Its size is in line with the Swedish study "Carried Fire Load in Mass Transport Systems" [5] and has been tested experimentally at the Material Research Centre Leipzig (MFPA) [6]. Details regarding these models see [3].

The maximum threshold times were defined in order to allow passenger and personal at any time to escape to a save area. A safe area is defined as follows by the German vfdb [7].
Table 1. Requirements for a safe area [7].

**ARGE Requirements on fire fighting**

The ARGE Guideline - Part 2 "Fire fighting in Rolling Stock" [3] focuses on the assessment of fire-fighting and fire extinguishing systems on railway vehicles by setting minimum requirements. It supports the selection of the extinguishing agent. The guideline requires a detection according to ARGE Part 1 [2], which automatically triggers the fire-fighting system after detection. For the requirement of the vehicle's continued ability to run in case of fire, the assessment must achieve:

- "Areas of relative safety" for affected persons in the passenger areas, at least by a fire fighting system which controls a fire, or
- "Areas of absolute safety" in equipment areas, by a fire extinguishing system.

**Extinguishing agent and equipment**

Extinguishing systems shall be systems that fully extinguish a fire in technical areas. These can be either gas extinguishing systems, water mist systems or aerosol systems. In passenger and staff areas generally water mist fire-fighting systems are used and recommended. Those systems do not necessarily fully extinguish a fire, but control it at a size in which it does not pose a life danger any more. It is not allowed to release substances of concern for health.

The assessment shall be done for gas and aerosol systems at a prototype vehicle or the first vehicle of a series, for water mist systems at mock-ups. For the passenger area a mock-up is defined which is considered conservative and allows the transfer of the result on any real vehicle with open passenger areas. Where applicable, the hardware shall be approved according to EN 12094.

**Assessment and thresholds for occupied areas**

The assessment of water mist fire-fighting systems should be done in a mock-up conservatively representing all passenger areas. Tests done in a real first series vehicle will be only valid for this vehicle class. Figure 3 shows the mock-up. It is conservative as the materials for seats and walls are formed of PUR foam blocks (400 mm x 400 mm x 100 mm) and wood, which is conservative compared to real materials on rail vehicles, which are barely ignitable following current regulations and standards as EN 45545-2:2013.
Fig. 3. Test mock-up and test position as well as fire sources acc. to [3]
The following four tests have to be performed for each testing position
- Travel bag test (see [3], [6]) two times
- Test with two PUR foam blocks (also called IMO cushion [8]), two times

The fire is always ignited using a paper cushion according to UIC 564-2 [9]. The pre-burning for each test is minimum 60 s. After the pre-burning team, the fire-fighting system is released manually. The four tests as above have to be carried out using different positions and interior arrangements
- Fire load on and under the seats
- Seat arrangements (wall mounted, bus-like or seats facing each other

For each test a fire positions has to be chosen, which is most unfavorable to the position of the nozzle of the fire-fighting system. The fire-fighting system should be operational for 10 minutes. During the whole test and until 30 minutes after the start of the test outside an area of maximum 2 meters around the fire location, the presence of persons must be possible. The target values of Table 1 shall not be exceeded within this period. This is monitored and measured according to figure 4.

Fig. 4. Measuring positions [3]

*Assessment and thresholds for technical areas*
In technical areas - differently form the passenger and staff areas - a full extinguishing of a fire is required. Possible extinguishing agents are gas, aerosol or water mist. Before the activation of the fire extinguishing system, the technical equipment in the affected area must be switched off. In areas with electric components, this concerns the complete electrical shutdown. In areas with combustion engines, this means to shut off the fuel supply and the engine. Air flows due to ventilation or train movement have to be taken into account.

For gas extinguishing agents only agents are allowed listed in EN 15004. The design concentration of this standard has to be proven by a concentration measurement. For water mist or aerosol extinguishing system a 1:1 extinguishing test is needed.
For combustion engines, there are three tests
- A spray fire with 0.0033 l/s fuel (15 s pre-burning)
- 1 m² diesel fire below engine (fire pan with 1800 kW; 60 s per-burning)
- 0.25 m² diesel fire below engine (fire pan with 380 kW; 60 s per-burning)

For other technical areas,
- Cable fire tests acc. To CEN/TS 14972:2008 ignites with 50 ml n-heptane (15 x 15 cm pan). Pre-burning ends when half of cable are on fire.
- A pool fire of the size 15 cm x 15 cm with 18 ml n-heptane and 2 ml toluene.

In addition the following requirements are to be met

<table>
<thead>
<tr>
<th>First extinguishing agent at nozzle after</th>
<th>Design concentr. achieved after</th>
<th>Holding time after reaching design concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquified gas extinguishant (e.g. Novec 1230)</td>
<td>10 s</td>
<td>20 s</td>
</tr>
<tr>
<td>Non-liquified gas extinguishant (e.g. nitrogen)</td>
<td>10 s</td>
<td>120 s</td>
</tr>
<tr>
<td>Water Mist</td>
<td>10 s</td>
<td>Min 120 s discharge duration</td>
</tr>
</tbody>
</table>

**Justification**
The use of the travel bag as representative fire source was justified above. The use of the IMO cushions (PUR blocks) was introduced to achieve better reproducibility in the testing of water mist fire-fighting systems for occupied areas. Even though the size and the packing an content of the travel bag is standardized (see [3]), fire-fighting results with travel bags have naturally a certain variety. Based on comparative tests (see figure 5) the test based on the PUR blocks has been developed. ARGE Part 3 is on the assessment of the system functionality and the integration on the train information system and not considered in this paper.

**Experience in ARGE Testing**
Since the first publication in 2008, the ARGE guidelines have been used in various projects by various manufacturers. Therefore experience in testing and assessment has been gained.

**Experience in Fire Detection Testing**
One main result of the experience gained, was that the use of methanol as means of smoke heating can lead to dangerous situation, especially in case of moving vehicles. Therefore - as mentioned above - the gas burner has been introduced as alternative means. Figure 6 shows an
example of the testing of fire detection systems in passenger compartments.

![Graph of heat release over time for different designs of fires.](image1)

**Fig. 5.** Comparison of travel bag design fire with PUR block fires.

![Images of different fire scenarios.](image2)

**Fig. 6.** Examples of ARGE fire detection testing in passenger areas [Wagner internal].

For smoke point-type detectors approved according to EN 54-7 this testing method allows a maximum distance of about 5 to 6 m. However this value is influenced and can be decreased due to air flow e.g. by heating or HVAC.
No clear prediction is possible on the effect of HVAC. In some cases – even in the same car with the same HVAC system – the presence of HVAC can decrease detection times, while in other positions it can increase detection times. See figure 7 for an example.

Fig. 7. Influence of HVAC on detection times [Wagner internal]

Generally it shows that ASD systems are less influenced by air movement’s due to HVAC or other reasons. This is due to the facts that the sampling points can be positioned so that they are monitoring smoke at the smoke extraction points into the HVAC systems (often above the line of windows). Furthermore the active air sampling makes them generally less influenced by air movements.

In case of moving vehicles with openable windows during test rides at 80 km/h it was observed that while ASD systems can still locate smoke in the correct fire detection zone, point-type detectors gave first alarm in a wrong zone due to smoke carryover. Experience on small compartments like electrical cabinets, show that the smoke generator test generally can be passed easily (example Fig. 8). The fog heater according to Fig. 2 is normally not needed.

Fig. 8. Smoke test in an electrical cabinet

Experience in fire fighting
Fire-fighting experiments with water mist in passenger areas have confirmed that testing in prototype vehicles is much easier to pass with positive results than testing on the mock-up built according to Fig. 3. This is understandable as in real newly constructed trains seats are
made of non-combustible materials according EN 44545-2, while the mock-up uses PUR blocks to simulate the seats. So the initial fire spread during pre-burning time is much bigger and the fire load much higher. Figure 9 shows picture of fire-fighting testing in a mock-up experiment. Figure 10 shows the example of travel bag fire-fighting test.

Fig. 9a  Before Test.  
Fig. 9b.  Pre-Burning Time.  
Fig. 9c.  During Fire Fighting.  
Fig. 9d.  After Test.

Fig. 10a.  Before Test.  
Fig. 10b.  Pre-Burning Time.  
Fig. 10c.  During Fire Fighting.  
Fig. 10d.  After Test [Wagner internal].
The fires are not always fully extinguished after the 10 minutes of water mist fire-fighting. However they are kept small and do not grow again, so that the conditions of Table 1 are met for 30 minutes. For meeting the requirements usually water quantities of less than 0.15 L/min/m³ are needed with a fine mist. Figure 11 shows the water mist formation.

**Fig. 11. Water Mist formation [Wagner internal].**

**UNI 11565 and Future European Standard**

Parallel to ARGE Italy has developed a national standard for assessing fire detection and fire-fighting systems. The currently valid edition is UNI 11565: 2016. The fire detection requirements are very similar to ARGE. As means of fire source either a smoke generator as in ARGE can be used or PUR blocks of 300 x 300 x 40 mm (smaller than one IMO cushion) can be used.

The detection times are as in the ARGE guidelines. Fire-fighting tests shall be done exclusively on mock-ups of the sizes:
- 12 m x 2.9 m x 2.5 m for open passenger areas
- 2.5 m x 2.5 m x 2.5 m for compartments

Test fires differ here from the ARGE guideline Part 2 [3]. Also here are two test fires needed. For the first with IMO cushions the fire source is only one IMO cushion (instead of two as in ARGE). Seats are made by IMO cushions as in ARGE (see figure 12).

**Fig. 12. IMO cushion fire test for water mist fire-fighting in UNI 11565.**
Additionally to ARGE a luggage rack with IMO cushions is introduced. These tests have to be carried out with different seat arrangements and different positions of the fire compared to the water mist nozzles (nozzle close to fire, fire in between two nozzles). The bag test is replaced by a metal tray put under the seat. This metal tray is shown in figure 13 and shall represent luggage.

Fig. 13. Metal tray to be positioned under seat acc. To UNI 11565 with (1 = Cotton, 2 = Paper, 3 = Polyamide).

Ignition source is ethanol (50 ml for IMO cushion test; 100 ml for luggage test). The pre-burning time is as in ARGE 60 seconds.

The success criteria are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>&quot;Heat&quot; test</th>
<th>&quot;Luggage&quot; test</th>
</tr>
</thead>
<tbody>
<tr>
<td>T_max</td>
<td>65°C</td>
<td>65°C</td>
</tr>
<tr>
<td>CO max</td>
<td>N/A</td>
<td>1400 ppm</td>
</tr>
<tr>
<td>CO₂ max</td>
<td>N/A</td>
<td>6% Vol.</td>
</tr>
<tr>
<td>HCN max</td>
<td>N/A</td>
<td>55 mg/m³</td>
</tr>
<tr>
<td>O₂ min</td>
<td>15% Vol.</td>
<td>15% Vol.</td>
</tr>
</tbody>
</table>

The values shall not be exceeded during the whole test. The observation time here is 20 minutes. Different from ARGE no minimum discharge duration is given. Figure 14 shows as an example results for a luggage test. The biggest difficulty is that during pre-burning an initial discharge the 65 °C are not exceeded at the measuring point directly at ceiling above the fire source. ARGE only has the measuring point in 1,6 m distance.

Fig. 14. Example of luggage fire-fighting test according to UNI 11565.
Comparison of our tests under both standards (ARGE guideline Part 2 and UNI 11565) show that it seems to be more effective for fire-fighting to discharge a given amount water in a shorter time than over a longer period of 10 minutes (as required by ARGE). An intensive knock down in the first 3 to 5 minutes may have a better fire reduction effect than a slower discharge over 10 minutes.

Currently CEN/TC 256 is working on a European standard for the assessment of “Fire Containment and Control Systems” (FCCS) on railway vehicles. Key focus here is the potential replacement of fire doors between railway cars by an FCCS which may be consisting of fire detection and fire-fighting systems. Target is to achieve the same performance as a fire door would give. This may lead to nouveau concepts like fire-fighting not over a whole car, but only at the connection between two cars. However this standard is not evolved far enough to give details. However it will certainly influence the future technologies.

References


[8] IMO A.800 (19) "Revised Guidelines for approval of sprinkler systems equivalent to that referred to in SOLAS regulation II-2/12" (November 1995).

Note: In chapter 6.4 of the standard, the requirements and characteristics for the fire object or reference fire load "IMO cushion" (polyether foam cushion) are defined.