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D6.5 Part 1 Validation of the conventional classification criteria proposed in WP3

Deliverable Report

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Authors:	Peter Briggs, Clare Barker, Beth Dean, Bjoern Bansemer, Michael Halfmann, Karl-Heinz Richter, Friedrich-Wilhelm Wittbecker, Tuula Hakkarainen, Esko Mikkola, Maria Hjohlman, Per Blomqvist, Alain Sainrat, Eric Guillaume, Silvio Messa, Claudio Baiocchi, Arnaud Marchais, Sylvie Guesdon, Heinz Reimann, Dave Tooley, Carlo Cecchi, Andreas Braetz, et al.
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	Name	Organization	Date	Visa
Coordinator	Alain Sainrat	LNE	15/11/2012	
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Section I - Executive summary

I.1 Description of the deliverable content and purpose

The objective of this task is to validate the conventional pragmatic classification criteria proposed in WP3 using data from 70 products and with the help of fire safety engineering principles developed in WP4, WP5 and WP6.

One-zone modelling of 70 products in single deck and double deck railway vehicles has been conducted so that a new classification system for the toxicity of fire gases from products installed on European trains could be proposed to the CEN/TC256 & CENELEC/TC9X Joint Working Group which will revise EN 45545-2 (1st Edition) to EN 45545-2 (2nd Edition).

The work has involved the development of new equations to calculate the FED and FEC of the gaseous effluents from the continuous gas measurements obtained in the EN ISO 5659-2 smoke chamber using FTIR spectrometry. The reaction to fire characterization of products in terms of their perceived burn areas was studied in 3 Task Groups. The location of these products on various European trains was also considered so that the conditions for fire tests (especially the ignition models) may simulate the end-use of the product and hence, the derived classification criteria can be seen to be relevant to real train environments. The classification system that has been developed is designed to relate to the compromised tenability of passengers who need to escape from a coach where a fire develops. This methodology is defined in ISO 13571 (2nd Edition).

I.2 Brief description of the state of the art and the innovation brought

From the previous research done in TRANSFEU WP3, some conclusions were drawn that suggested a need to revise EN 45545-2 (1st Edition): -

a) Few deviations in pass/fail results are reported but generally the classification of the 70 products is not modified too much by comparison with the CEN/TS 45545-2 .

b) The ASET results should make it easier to determine compliance with the requirements of operation categories for trains on European networks. The TRANSFEU D3.4 method gave better discrimination than the CEN/TS 45545-2 method because the shape of the CIT versus time curve is very important, as well as the time to CIT =1. The method in CEN/TS 45545-2 measures the CIT value at 4 minutes and 8 minutes. Where a product gives a value of CIT = 1 at less than 4 minutes or between 4 and 8 minutes, this behaviour could be missed and the product assumed to have passed.

c) The EN ISO 5659-2 procedure coupled with continuous FTIR gas analysis should be considered further by the CEN/TC256 and CENELEC/TC9X Joint Working Group. TRANSFEU proposed in June 2011 that this procedure should be incorporated into EN 45545-2.

I.3 Deviation from objectives

None

I.4 Corrective actions

Not relevant

I.5 Intellectual property rights

None known

Section II - Objectives of Task 6.5

II.1. General

The objective of this task is to validate the conventional pragmatic classification criteria proposed in WP3 using data from 70 products tested to the ISO 5659-2/FTIR procedure as developed in WP2, with the help of fire safety engineering principles outlined in WP4 and WP5, and the large-scale and real-scale tests conducted on products in railway coaches in WP6.

The participants in WP6.5 have worked in 3 Task Groups. Each Group studied a wide cross section of typical European railway vehicle products which would in future have to be compliant with the requirements of EN 455455-2 as specified in EC TSI regulatory documents. The composition of these Groups was as follows:-

Group A	Exova Warringtonfire, LNE and RATP
Group B	Currenta, SP and RATP
Group C	VTT, LSF and RATP

II.2. WP3 background

1. As reported in WP3.1, WP3.2, WP3.3 and WP3.4 delivered reports (see references 1, 2, 3 and 4), the main objective of the required classification system for gaseous effluents can be achieved by continuously analysing the gases from the ISO 5659-2 chamber and using the test data to calculate toxicity indices.

In Tasks 3.3 and 3.4 when CIT calculations have been carried out, the reference gas concentrations used have been the same as those detailed in CEN/TS 45545-2. These values are based on IDLH (Immediately Dangerous to Life and Health), which is recognized as a limit for personal exposure to the gas component by NIOSH (USA National Institute for Occupational Safety and Health (1997 version).

In TRANSFEU Task 6.5, the NIOSH reference gas concentrations have been replaced by concentrations which are expected to seriously compromise the ability of exposed occupants to escape from a fire in a rail coach. These gas concentrations are specified in ISO 13571 (2nd Edition, September 2012).

2. Specifications of product parameters for CIT calculations in Task 3.4 were agreed based on the results of Task 3.3 and on the perceived requirements of the CEN CENELEC JWG. Hence, in these 1-zone model calculations, the volume of a coach (for both single deck and double deck vehicles) was assumed to be 150m^3 and the ventilation to the coach as 0m^3/s. The ASET for all products was calculated according to their time to CIT = 1 and the suitability of these products for use in various operation categories of railway vehicle were determined according to the RSET values of 2 minutes and 4 minutes.

3. The essential requirements for the fire behaviour of materials and components installed in railway vehicles are defined in CEN/TS 45545-2 clause 4 and the specifications are shown in Tables 4 and 7 of CEN/TS 45545-2. The requirements for listed products are assigned R numbers in Table 4 and the set of reaction to fire parameters required to define the HL performance of a product are detailed in Table 7. These prescriptive requirements are based on test results from flame spread, heat release and smoke opacity data obtained from standard tests carried out under laboratory conditions that simulate the realistic end-use installation of the product on a railway vehicle. The requirements for toxicity of fire effluents from these listed products are based on CIT test data obtained from single point sampling of the gases at 4 minutes and 8 minutes in the ISO 5659-2 smoke chamber. Alternatively, for certain products (such as cables, small electrotechnical and minor non-listed products), test data from the NF X70-100-2 tube furnace is permitted.

In the D3.4 report, recommendations for determining the time to CIT = 1 for exposed products are tabulated with the prescribed CEN/TS 45545-2 requirements for all the product sectors examined in TRANSFEU WP3. It should be understood that, at this stage 1 of the TRANSFEU programme, no considerations have been applied to changes in the flame spread, heat release or optical density specifications for listed products. However, there is strong support for a more relevant method for classification of the toxicity of fire effluents for use when determining the HL performance requirements of listed products. This method is available by combining the ISO 5659-2 smoke chamber measurements with continuous analysis of combustion gases using FTIR spectrometry.

4. The situation concerning WP3.4 showed that the testing and continuous gas analysis of 60 train products has been a good step forward. The results of the toxicity classifications based on ASET using time to CIT = 1 as the failure criterion were compared with the prescribed CEN/TS 45545-2 classifications based on CIT values determined at 4 minutes and 8 minutes during the EN ISO 5659-2/ FTIR smoke chamber test.

II.3. Refinements to the modelling approach

1. Further improvements to the classification system developed in WP3 require more accurate derivations of the gas-data than time to CIT = 1. ASET can be better estimated according to ISO 13571 principles and further validations can then be conducted based on the results of full-scale and real-scale tests.

2. In order to achieve the WP6.5 objectives, the continuous gas concentration/time data for the 70 TRANSFEU products had to be revisited and the toxicity criteria based on FED and FEC had to be reassessed. The changes to the equations used in calculating FED and FEC are described in Section III of this report and their effect on the way to derive a classification system using time to compromised tenability are detailed in Section IV.

Section III - Refinements to the modelling approach for the gas summation terms

III.1. Toxic effects of fire gases

There are essentially three kinds of acute toxic effects which may result from an exposure to fire effluents:-

- **Asphyxiation.**
  The inhalation of asphyxiant gases (such as CO or HCN) causes hypoxia in the body tissues, especially the brain, which may result in incapacitation or death. Asphyxiant effects depend on accumulated doses, i.e. they relate to both the concentration of the gas and the duration of the exposure (exposure dose).
- **Sensory irritation.**

Irritant fire gases (such as HCl or NO_X) can produce painful effects to the eyes and the upper respiratory tract, which may impair the ability to escape or even result in incapacitation. Since sensory irritation occurs immediately on exposure, these effects are considered to depend on concentrations rather than on doses.

- **Pulmonary irritation.**
  Irritants penetrating into the lung can cause pulmonary irritation effects that may lead to respiratory distress and, potentially, to post-exposure death (e.g. due to oedema). As with asphyxiant fire gases, pulmonary irritation effects are considered to be dose-related.

The two major asphyxiant fire gases are CO and HCN, with CO intoxication being considered the main cause of death in fires. The toxic potency of CO_2 is comparatively low and usually not taken into account in fire hazard analyses. However, CO_2 stimulates breathing and can therefore increase the uptake of other gases present in the fire atmosphere. Furthermore, hypoxia may also be caused by an exposure to low oxygen concentrations.

Narcotic effects of fire effluents are normally attributed to these few gases, whereas a large number of fire gases have been identified to cause irritancy. Important irritant fire gases are HCl, HBr, HF, NO_X, SO_2 and organic aldehydes (such as acrolein and formaldehyde).

III.2. Estimation of toxic hazard in fires

For a given fire scenario, a toxic hazard analysis can be performed using the concept of Fractional Effective Dose (FED) and Fractional Effective Concentration (FEC). This approach represents the state-of-the-art methodology for determining the Available Safe Escape Time (ASET) in fire safety design calculations. The following equations are for predicting toxic effects, but the FED/FEC concept can also be used for assessing thermal and visibility-reducing effects of fire atmospheres (which are not considered in this report).

In inhalation toxicology, analyses are usually based on exposure doses rather than on (organ) absorbed doses. Exposure doses are calculated as the product of the toxicant concentration and the exposure time:

(1) $$Ct(t) = c \cdot t$$

where

Ct exposure dose (ppm·min)

c (constant) concentration of the toxicant in the inhalation atmosphere (ppm)

t duration of exposure (min)

For concentrations varying with time, the exposure dose is obtained by integrating the concentration-time curve over time (i.e. by calculating the product of concentration and time for each small time step $d\tau$):

(2) $$Ct(t) = \int_{t_0}^{t} c(\tau)\,\mathrm{d}\tau$$

where t_0 represents the beginning of the exposure.

Thus, the exposure dose, Ct, increases continuously during exposure. The FED is the ratio of the dose received at a time t during exposure and the dose that causes a particular toxic effect.

(3) $$FED(t) = \frac{\text{dose received at time } t}{\text{effective dose}} = \int_{t_0}^{t} \frac{c(\tau)}{Ct_{\text{eff}}}\,\mathrm{d}\tau$$

At that point in time when the FED reaches unity (received dose = effective dose), the toxic effect is predicted to occur.

For a given toxicant, the effective dose, Ct_{eff}, may have different values depending upon which toxic effect or, respectively, endpoint is considered. For example, the exposure dose for CO causing incapacitation (in half of the population) is usually taken to be 35000 ppm·min whereas the lethal dose is expected to be approximately twice to three times as large.

Dose-effect-models are often based on Haber's rule which states that, for a given toxicant, different concentrations and different exposure times will produce the same toxic effect if the product of concentration and time is the same:

(4) $$Ct_{\text{eff}} = c \cdot t = \text{const}$$

That means that a concentration of, for example, 500 ppm exposed for 30 min will produce the same effect as a concentration of 1000 ppm exposed for 15 min. The dose is 15000 ppm·min in both cases. For toxicants obeying Haber's rule the denominator in equation (3) is, accordingly, a constant.

Fire atmospheres usually contain many different toxic gas components which act simultaneously. A commonly accepted approach is to consider the effects of the individual gases directly additive, i.e. to assume that they act independently from each other. The total FED then results from the summation of the single FEDs calculated for each gas component i:

(5) $$FED(t) = \sum_{i=1}^{n} \int_{t_0}^{t} \frac{c_i(\tau)}{Ct_{\text{eff},i}}\,\mathrm{d}\tau$$

For toxic effects which depend only on the concentration of the toxicant, such as sensory irritation, the FEC concept applies:

(6) $$FEC(t) = \frac{\text{concentration at time } t}{\text{effective concentration}} = \frac{c(t)}{c_{\text{eff}}}$$

where c_{eff} may relate to different tenability endpoints, e.g. impairment of escape efficiency or incapacitation. Assuming additivity of effects, the FEC for a combination of toxicants is given by:

(7) $$FEC(t) = \sum_{i=1}^{n} \frac{c_i(t)}{c_{\text{eff},i}}$$

III.3. Calculation method for ASET according to ISO 13571

Using the FED/FEC concept described above, ISO 13571 [8] provides a calculation method for estimating the time available for occupants to escape from a fire (i.e. ASET). The method examines both the asphyxiant effect (based on an FED calculation) and the irritant effect (based on an FEC calculation) of fire gases. The time available for escape depends on which effect is predicted to occur first.

Asphyxiation.

For estimating the time to incapacitation caused by the asphyxiant gases CO and HCN, fractions of an incapacitating dose are calculated for each discrete time interval:

(8) $$\Delta FED = \Delta FED_{\text{CO}} + \Delta FED_{\text{HCN}}$$

where

ΔFED Fraction of an incapacitating dose of all asphyxiant gases (-)

ΔFED_{CO} Fraction of an incapacitating dose of CO (-)

ΔFED_{HCN} Fraction of an incapacitating dose of HCN (-)

The dose fractions of CO and HCN are given by:

(9) $$\Delta FED_{\text{CO}} = \frac{V_{\text{CO}_2} \cdot c_{\text{CO}}}{35000 \text{ ppm} \cdot \text{min}} \Delta t$$

(10) ISO 13571 (2nd Edition; 2012): $$\Delta FED_{\text{HCN}} = \frac{V_{\text{CO}_2} \cdot c_{\text{HCN}}^{2.36}}{1.2x10^6 \, \text{ppm}^{2.36} \cdot \text{min}} \Delta t$$

NOTES on Equation 10:

a) In ISO 13571 (1st Edition; 2007), equation 10 is written as

$$\Delta FED_{\text{HCN}} = \frac{V_{\text{CO}_2} \cdot \exp\left(c_{\text{HCN}} / 43 \, \text{ppm}\right)}{220 \, \text{min}} \Delta t$$

b) When revising ISO 13571, this equation was modified to that below at the DIS 13571 stage of the 2nd Edition

$$\Delta FED_{\text{HCN}} = \frac{V_{\text{CO}_2} \cdot c_{\text{HCN}}^{2.36}}{10^6 \, \text{ppm}^{2.36} \cdot \text{min}} \Delta t$$

c) After further discussion in ISO/TC92/SC3/WG5 during 2012, the denominator of this HCN term was further modified as shown in equation 10, which now applies to ISO 13571 (Edition 2; September 2012). This equation has subsequently been used in this project when calculating the fractional dose of HCN.

d) The three different versions of equation 10 have been considered in detail during this research. The use of the correct equation is important because it affects the overall FED as exemplified by Figure 1.

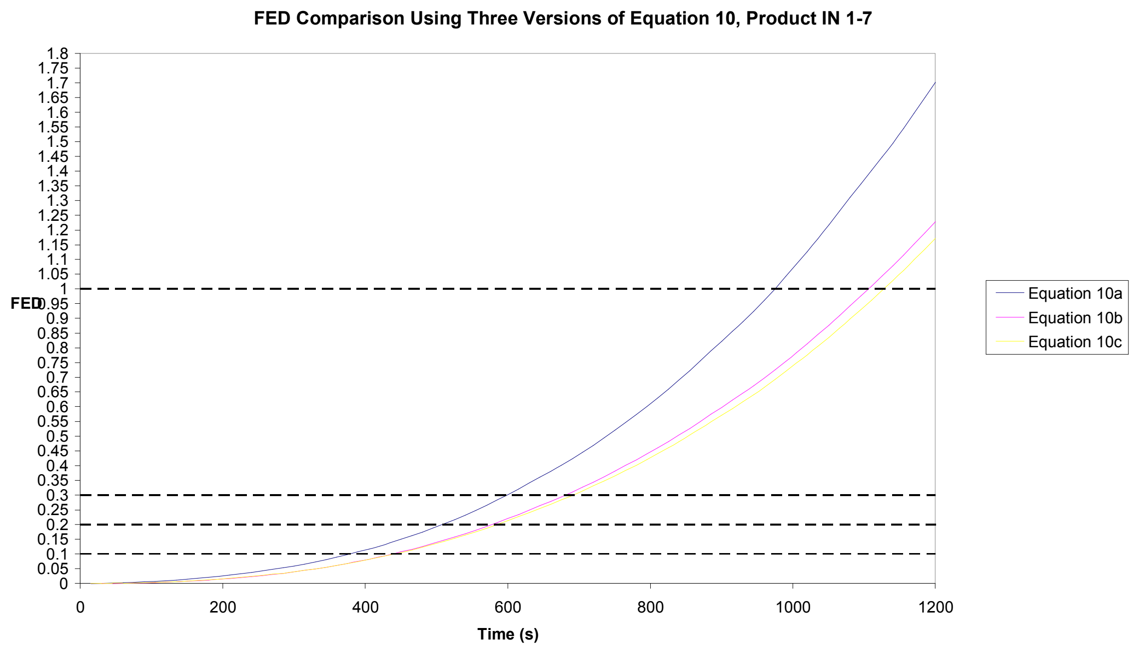


Figure 1: Visual representation of the impact on FED when various versions of equation 10 are used to calculate the dose fractions of HCN.

(11) $$V_{CO_2} = \exp\left(\frac{c_{CO_2}}{50000\,\text{ppm}}\right)$$

where c_{CO}, c_{HCN} and c_{CO_2} are the average concentrations, expressed in ppm, of the respective gas components over the time increment Δt, expressed in minutes. The multiplication factor V_{CO_2} takes into account the effect of CO_2-induced hyperventilation.

The total FED is obtained by summing over time the dose fractions from Equation (8):

(12) $$FED(t) = \sum_{t_0}^{t} \Delta FED(\tau)$$

For calculations in TRANSFEU Task 6.5: -

Sensory irritation.

Sensory irritation effects are assumed to occur when the FEC reaches unity:

$$(13) \qquad FEC(t) = \frac{c_{\mathrm{HCl}}(t)}{c_{\mathrm{eff,HCl}}} + \frac{c_{\mathrm{HBr}}(t)}{c_{\mathrm{eff,HBr}}} + \frac{c_{\mathrm{HF}}(t)}{c_{\mathrm{eff,HF}}} + \frac{c_{\mathrm{SO_2}}(t)}{c_{\mathrm{eff,SO_2}}} + \frac{c_{\mathrm{NO_2}}(t)}{c_{\mathrm{eff,NO_2}}} + \frac{c_{\mathrm{acrolein}}(t)}{c_{\mathrm{eff,acrolein}}} + \frac{c_{\mathrm{formaldehyde}}(t)}{c_{\mathrm{eff,formaldehyde}}}$$

The effective concentrations, c_{eff}, of the individual irritant gas components are “expected to seriously compromise occupants’ tenability” [15]. The respective values are given in Table 1 (Section III.5).

III.4. Margins of safety

Susceptibility to fire gas toxicants varies among the human population. The effective (i.e. incapacitating) doses and concentrations given in ISO 13571 apply to individuals of average susceptibility. Accordingly, FED/FEC values of 1.0 correspond to situations where, statistically, only one-half of the population would be expected to experience tenable conditions when evacuating from a fire on a railway vehicle. In order to protect persons who exhibit a greater than average susceptibility it is necessary to establish FED/FEC threshold criteria < 1.0. Based on the assumption of a log-normal distribution of human responses to fire gas toxicants, ISO 13571 states that FED/FEC threshold criteria of 0.3 translate to 11.4 % of the population being susceptible and therefore statistically estimated to experience compromised tenability. This means that only 11.4% of the population might be unable to perform cognitive and motor-skill functions at an acceptable level during an evacuation. Users of ISO 13571 have the flexibility to select other FED and/or FEC threshold criteria as may be appropriate for fire safety objectives. These may be intended to reduce the percentage of the population which would be estimated to experience compromised tenability. For example, FED/FEC threshold criteria of 0.1 translate to only 1.1 % of the population being more susceptible and, therefore, statistically estimated to experience compromised tenability. However, it should be understood that whatever FED and FEC threshold criteria are decided, it is necessary to use a single value in any estimation of the time to compromised tenability.

III.5. Proposal for an improved classification system

The classification system initially proposed here is based on the calculation method provided in ISO 13571 [8], which is well-established and has been specifically developed for the assessment of toxic hazard in fires. This method is applied to the 1-zone coach model developed in TRANSFEU WP3.

The following FED equation is used for the asphyxiant gases CO and HCN[1].

[1] For HCN, see Notes on Equation (10) in Section III.3.

(14) $$FED(t) = \sum_{t_0}^{t} \frac{V_{CO_2}(\tau) \cdot f \cdot c_{CO}(\tau)}{35000\,\text{ppm} \cdot \text{min}} \Delta\tau + \sum_{t_0}^{t} \frac{V_{CO_2}(\tau) \cdot [f \cdot c_{HCN}(\tau)]^{2.36}}{1.2 \cdot 10^6\,\text{ppm}^{2.36} \cdot \text{min}} \Delta\tau$$

where

t test/exposure time (min)

f scaling factor (-) as given in Equation (15)

V_{CO_2} factor for CO_2-induced hyperventilation (-) as given in Equation (16)

c_{CO} average concentration (ppm) of CO in the ISO 5659 chamber over the time increment $\Delta\tau$

c_{HCN} average concentration (ppm) of HCN in the ISO 5659 chamber over the time increment $\Delta\tau$

(15) $$f = \frac{A_s \cdot 0.51\text{m}^3}{V_{coach} \cdot 0.004225\,\text{m}^2}$$

where

A_s is the surface area of the product that is perceived to burn (m^2), as described in CEN/TS 45545-2 Annex C.16,

V_{coach} is the volume (m^3) into which the fire effluents are assumed to disperse in the 1-zone coach model.

(16) $$V_{CO_2}(\tau) = \exp\left(\frac{f \cdot c_{CO_2}(\tau)}{50000\,\text{ppm}}\right)$$

where

c_{CO_2} average concentration (ppm) of CO_2 in the ISO 5659 chamber over the time increment $\Delta\tau$

For sensory irritation, the following FEC equation applies to the 1-zone model.

(17) $$FEC(t) = f \cdot \sum_{i=1}^{7} \frac{c_i(t)}{c_{\text{ref},i}}$$

where

t test/exposure time (min)

f scaling factor (-) as given in Equation (15)

c_i concentration (ppm) of gas component i in the ISO 5659 chamber at time t

$c_{\text{ref},i}$ reference concentration (ppm) of irritant gas component i according to Table 1.

Table 1: Reference concentrations of irritant gases for use in Equation (17)*

i	**Gas component**	**Concentration expected to seriously compromise occupants' tenability [8] (ppm)**
1	HCl	1000
2	HBr	1000
3	HF	500
4	SO_2	150
5	NO_2	250
6	Acrolein	30
7	Formaldehyde	250

**Gases 6 and 7 have not been included in the final calculations on the 70 products of this project (see Section III.6).*

The product classification/assessment procedure may then be envisaged as follows:

1. Calculate $\text{FED}(t)$ and $\text{FEC}(t)$ according to Equations (14) and (17) from the concentration-time curves determined for the individual gas components in the ISO 5659 chamber.
2. For both $\text{FED}(t)$ and $\text{FEC}(t)$, determine the time t at which a defined threshold value, for example 0.3, is reached. The smaller of the two time periods is ASET, i.e.

   ASET = min [t (FED=0.3), t (FEC=0.3)].
3. Compare ASET with RSET, where RSET depends on the Operation Category or Hazard Level of the vehicle on which the tested product shall be used. The requirement is

   ASET > RSET.

III.6. Selection of gases to use in the Summation Term of FEC calculations

The determination of FEC in Section III.5 is based on equation 4 of ISO 13571 which considers the concentration of hydrogen chloride, hydrogen bromide, hydrogen fluoride, sulphur dioxide, nitrous oxides, acrolein and formaldehyde, i.e. 7 irritant gases: -

$$FEC(t) = \frac{c_{\text{HCl}}(t)}{c_{\text{eff, HCl}}} + \frac{c_{\text{HBr}}(t)}{c_{\text{eff, HBr}}} + \frac{c_{\text{HF}}(t)}{c_{\text{eff, HF}}} + \frac{c_{\text{SO}_2}(t)}{c_{\text{eff, SO}_2}} + \frac{c_{\text{NO}_2}(t)}{c_{\text{eff, NO}_2}} + \frac{c_{\text{acrolein}}(t)}{c_{\text{eff, acrolein}}} + \frac{c_{\text{formaldehyde}}(t)}{c_{\text{eff, formaldehyde}}}$$

After considerable research in TRANSFEU and other laboratories (see test results in TRANSFEU D6.5 Part 2 Annex A), it was decided to modify the equation detailed in ISO 13571 such that the concentration of acrolein and formaldehyde were excluded: -

$$FEC(t) = \frac{c_{\text{HCl}}(t)}{c_{\text{eff, HCl}}} + \frac{c_{\text{HBr}}(t)}{c_{\text{eff, HBr}}} + \frac{c_{\text{HF}}(t)}{c_{\text{eff, HF}}} + \frac{c_{\text{SO}_2}(t)}{c_{\text{eff, SO}_2}} + \frac{c_{\text{NO}_2}(t)}{c_{\text{eff, NO}_2}}$$

The primary reason that acrolein and formaldehyde were excluded was because during the TRANSFEU full scale and real scale tests used to validate the results obtained, these two species were not detected. ISO 13571 states that the species included in equation 4 are not definitive and that the species detected for analysis should be broad enough to cover those species of toxicological significance that can reasonably be expected to be released.

In addition to these results, the repeatability and reproducibility of FTIR analysis of acrolein and formaldehyde during the small scale ISO 5659-2 tests could not be determined because there was insufficient data. Most laboratories taking part in WP2 had not calibrated their FTIR for the measurement of acrolein and formaldehyde.

Section IV- Refinements to the scaling factor for use in FED and FEC calculations

IV.1. General

In previous Tasks 3.3 and 3.4 when CIT calculations have been conducted using a 1-zone model of a rail coach, a burning area A_s m^2 has been introduced to link the area of a product perceived to be burning in a 150m^3 virtual coach to a test specimen of the product burning in the ISO 5659-2 smoke chamber. This link has been pragmatically related to an estimated potential burn area of the product when it has been exposed to a possible real ignition source (such as rolled-up newspaper or an item of luggage). It is proposed that a similar approach should be taken initially when calculating FED and FEC according to the guidance provided in ISO 13571.

It should be noted that, in progressing CEN/TS 45545-2 to prEN 45545-2, the JWG decided to keep A_s as 0.1m^2 for <u>all</u> products. Hence, TRANSFEU proposals for scaling factors will have to be considered at the revision stage of EN 45545-2 during 2013 – 2015.

IV.2. Scaling factors used in Tasks 3.3 and 3.4

IV 2.1 Lining products

The perceived burn area A_s was taken as 0.1m^2, 0.2m^2 or 0.7m^2 depending on the product concerned.

IV 2.2 Seats and furnishing products

The perceived burn area A_s was usually taken as 0.1m^2 (as in CEN/TS 45545-2). For some products such as seat backs, A_s may be more realistically taken as 0.7m^2.

IV 2.3 Electrotechnical products

The perceived burn area A_s was generally taken as 0.1m^2 for electrotechnical products or 0.2m^2 for conduit.

IV 2.4 Cables

The basic equation used for cables for the calculation of CIT_C is developed from the formula for CIT_G but it is adjusted to another fire test method used when measuring the gas concentrations in the fire effluents. The equation for the one zone model considered in Task 3.4 is as follows:

$$CIT_{C(t+\Delta t)} = CIT_{C,t} \times \left(\frac{V_{coach} - Q_{air}.\Delta t}{V_{coach}} \right) + \frac{\dot{V}(t)}{V_{coach}} \sum_{i=1}^{8} \frac{c_i(t)}{C_i} \times \Delta t$$

where

$\dot{V}(t)$ is the flow of exhaust gases at the sampling point in the prEN 50399 test apparatus (m^3/s)

$c_i(t)$ is the concentration of gas i (mg/m^3)

Since all calculations were performed with V_{coach} = 150m^3 and Q_{air} = 0m^3/s, the above equation simplifies to:

$$CIT_{C,t+\Delta t} = CIT_{C,t} + \frac{\dot{V}(t)}{V_{coach}} \sum_{i=1}^{8} \frac{c_i(t)}{C_i} \times \Delta t$$

where the scaling factor is $\frac{\dot{V}(t)}{V_{coach}}$

IV 2.5 Non-listed products

The basic equation used for non-listed products for the calculation of CIT_{NLP} is developed from the formula for CIT_G. Since the non-listed products may have any arbitrary shape, masses are used as scaling factors instead of areas. The equation for the one zone model considered in Task 3.4 is given below:

$$CIT_{NLP(t+\Delta t)} = CIT_{NLP,t} \times \left(\frac{V_{coach} - Q_{air}.\Delta t}{V_{coach}} \right) + \frac{0.51m^3 \times w_a}{V_{coach} \times w_s} \sum_{i=1}^{8} \frac{\dot{c}_i(t)}{C_i} \times \Delta t$$

where:

w_a is the estimated mass of the product present in 0.1m^2 perceived burn area in the coach (g)

w_s is the total initial mass of the specimen before testing in the ISO 5659-2 smoke chamber (g)

Since all calculations are performed with V_{coach} = 150m^3 and Q_{air} = 0m^3/s, the above equation simplifies to

$$CIT_{NLP(t)} = \frac{0.51m^3 \times w_a}{V_{coach} \times w_s} \sum_{i=1}^{8} \frac{c_i(t)}{C_i}$$

where the scaling factor is $\frac{0.51m^3 \times w_a}{V_{coach} \times w_s}$

IV.3. Scaling factors used in Task 6.5

IV 3.1 General

The development of the rules for the selection of scaling factors has been done pragmatically in Task 6.5 and wherever possible the proposals applying to particular product sectors has been assessed by reference to prior research as well as to the full-scale and real-scale results obtained in the TRANSFEU project. Extra input into the perceived areas of products burning in real-scale tests has come from numerical calculations for wall linings and seats in Task 6.

IV 3.2 Rule 1

The scaling factors specified for Tasks 3.3 and 3.4 were initially defined on the basis of the potential realistic area of the products installed in a coach and on the probability of accidental or minor arson attacks on these products. Estimates of typical installed areas of products in a rail coach have been made and these areas have been assumed to reflect the operational risk in Task 6.5.

IV 3.3 Rule 2

The perceived areas of installed products that may be burnt by various ignition sources have been determined in full-scale and real-scale tests:-

- A perceived burn area of 0.1m^2 is associated with ignition models 1, 2, 3 and 4 as defined in CEN/TS 45545-1 Annex A. These sources may also be considered as Type 1 according to EN 50553.
- For situations when a fire may grow so that a more serious ignition source could develop (described as Type 2 sources such as a burning seat or piece of luggage), the perceived burn area of a product A_s is taken as 0.7m^2 in CEN/TS 45545-1.

In Task 6.5 it has been assumed that the above perceived burn areas apply to most lining products, seats and furnishings and some electrical products (refer to Tables 2, 3 and 4); these values have been used in calculations of FED and FEC.

Table 2 – Perceived burn areas for lining products

Product number according to CEN TS 45545-2	Description of end-uses for products	Perceived Burn Area of Product considered in Task 3.4 (m^2)	Perceived Burn Area of Product considered in Task 6.5 (m^2)
IN1	Interior walls and ceilings	0.7	0.2 and 0.7
IN3	Vertical cover strips and light diffusers	0.2	0.2
IN6	Interior surfaces of gangways (Type B where there is a fire barrier at both bulkhead sides of the gangway)	0.7	0.7
IN10A	Top surface of tables and toilet wash basins	0.1	0.2
IN12	Interior surface of air ducts which are connected to the interior of the vehicle	0.7	0.7
IN14	Air filter materials for heating, ventilation and air conditioning (HVAC) equipment	0.1	0.1
IN16	Floor composites including floor substrate, insulation and floor covering (with or without adhesive as specified)	0.1	0.1
EX1A	Walls of external body shell (including paint and cover films)	0.7	0.7
EX1B	External cab housing (including paint and cover films)	0.7	0.7
EX3	Under frame of external body shell (including paint and protective coatings or floor panelling)	0.7	0.7

Table 3 – Perceived burn areas for seats and furnishing products

Product number according to CEN TS45545-2	Description of end-uses for products	Perceived Burn Area of Product considered in Task 3.4 (m^2)	Perceived Burn Area of Product considered in Task 6.5 (m^2)
IN8	Curtains and sun blinds in passenger and staff areas (except those enclosed within a double glazed window)	0.7	0.7
F1A	Upholstery for passenger seats and head rests	0.1	0.2 and 0.7
F1B	Top surface of armrests for passenger seats	0.1	0.1
F1E-1	Seat shell base of passenger seat	0.1	0.1
F1E-2	Seat shell back of passenger seat	0.7	0.7
F3	Mattresses	0.7	0.7
F5	Underside surfaces of couchettes and beds	0.7	0.7

Table 4 – Perceived burn areas for electrical products

Product number according to CEN TS45545-2	Description of end-uses of products	Perceived Burn Area of Product considered in Task 3.4 (m^2)	Perceived Burn Area of Product considered in Task 6.5 (m^2)
IN2	Limited surfaces of products on walls or ceilings. For walls, their maximum dimension vertically is 1m. For ceilings, their area is < $0.2m^2$.	0.1	0.1
E1A-1	Cables for interior installation – these may be power cables or control/communication cables	As in EN 50399 test	As in EN 50399 test
E1A-2	Cables for exterior installation – these may be power cables or control/communication cables	As in EN 50399 test	As in EN 50399 test
E2A	Interior cable containment such as cable duct or conduit	0.2	0.2
E4A	Arc resistant insulation materials (Type A as defined in TS 45545-5)	0.1	0.1
E7A	Components for interior electrical supply line system and high power devices (such as isolators, current and voltage transformers, main circuit breakers, contactors)	0.1	0.1

IV 3.4 Rule 3

3.4 a) During the Task 6.5 studies it was decided that additional derivations should apply in the future in the specification of perceived burn areas when calculating FED and FEC for products involved in fires on surface transport. This requirement should be an experimental determination of the propensity of a product to spread flame.

3.4 b) For large area products (such as linings on walls and ceilings) this A_s parameter may be derived from the critical flux at extinguishment (CFE) as measured in the ISO 5658-2 radiant panel test (ref.27). For flooring composites the critical radiant flux determined in the EN ISO 9239-1 test (ref.29) may be used to derive the A_s parameter. It is also noted that CEN/TS 45545-2 specifies the use of ISO 5658-2 for other product sectors (see Table 5).

Table 5 – Flame spread requirements for products in CEN TS 45545-2

Product Sector	**Typical products**	**Critical Flux at Extinguishment (CFE) in kW/m^2** **Minimum for all HL categories**
IN1 IN4 IN5 IN6 IN7 IN8 IN10B IN12 IN15	Walls, ceilings Luggage storage areas Driver's desk Interior surface of gangways Window frame Curtains and sun blinds Table tops (bottom surface) Interior surface of air ducts Devices for passenger information	20
IN2 IN3 IN10A	Limited surfaces Strips and light diffusers Table tops (upward surface)	13
EX1A EX3 EX4 EX7	External body shell, walls External body shell, Under frame Exterior ducts Outer membrane of intercommunication gangways	20
F5	Underside surface of couchettes and beds	20
E2A E3 E4A E4B	Interior cable conduit Enclosures for electrical equipment Arc resistant insulation materials, Type A Arc resistant insulation materials, Type B	20 20 30 40

The test burnt areas shown in Figures 2 and 3 are calculated from the irradiance/distance calibration graphs that every fire laboratory has to determine when conducting the ISO 5658-2 and ISO 9239-1 tests. To derive the perceived burn area A_s for railway vehicle products in end-use conditions, the measured test burnt areas have to multiplied by an additional factor n which takes into account the potential for a real-scale product to spread flame in several directions (e.g. laterally to left and right for wall linings and floorings, upwards for wall linings and sideways for floorings). In the Task 6.5 studies, n is assumed to be 3.

Figure 2 – Burnt area of test specimen in ISO 5658-2 versus critical radiant flux

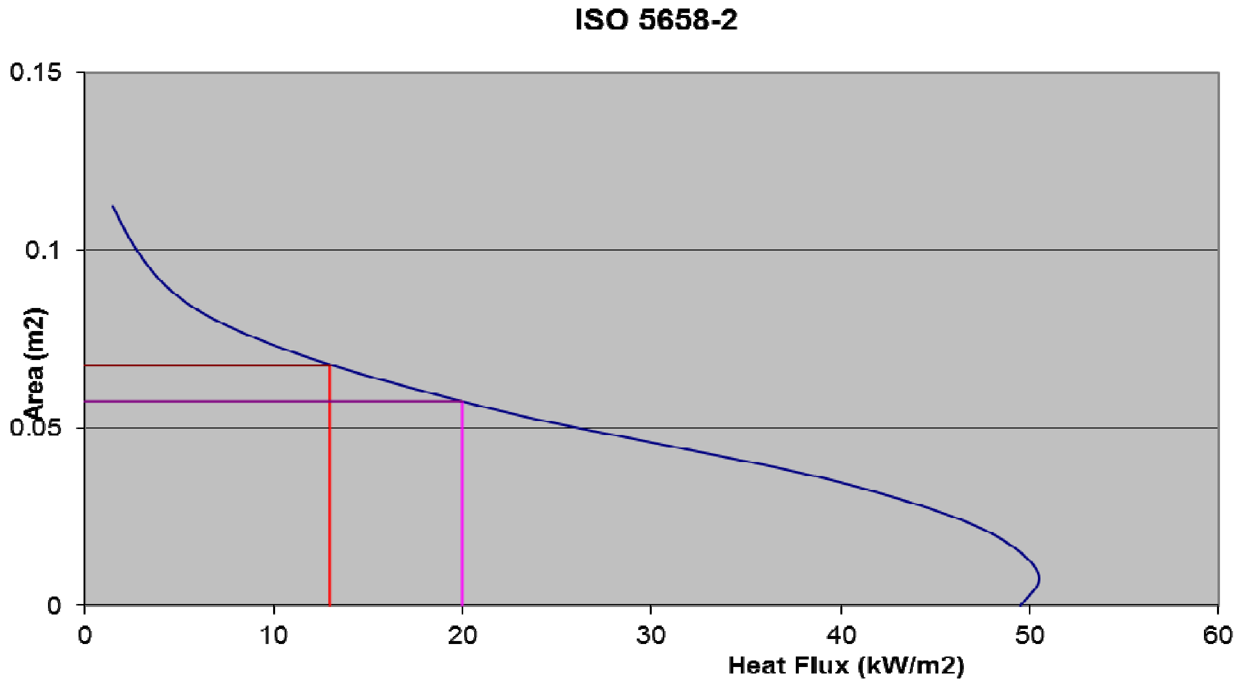


Table 6 – Use of ISO 5658-2 for determination of A_s for wall linings

Critical Flux (kWm^{-2})	Burnt area of test specimen (m^2)	Perceived burn area of lining A_s (m^2)
40	0.035	0.10
30	0.047	0.14
20	0.057	0.17
13	0.068	0.20

It is proposed that Table 6 could be used to specify the perceived burn area A_s for wall linings when selecting the scaling factor to be used when calculating FED and FEC. For example, the following criteria for A_s could be considered for IN1 products in various operation categories of railway vehicle:-

HL1 $0.17m^2$
HL2 $0.14m^2$
HL3 $0.10m^2$

For IN2 limited surface products, the A_s criterion could be $0.20m^2$.

Figure 3 – Burnt area of test specimen in ISO 9239-1 versus critical radiant flux

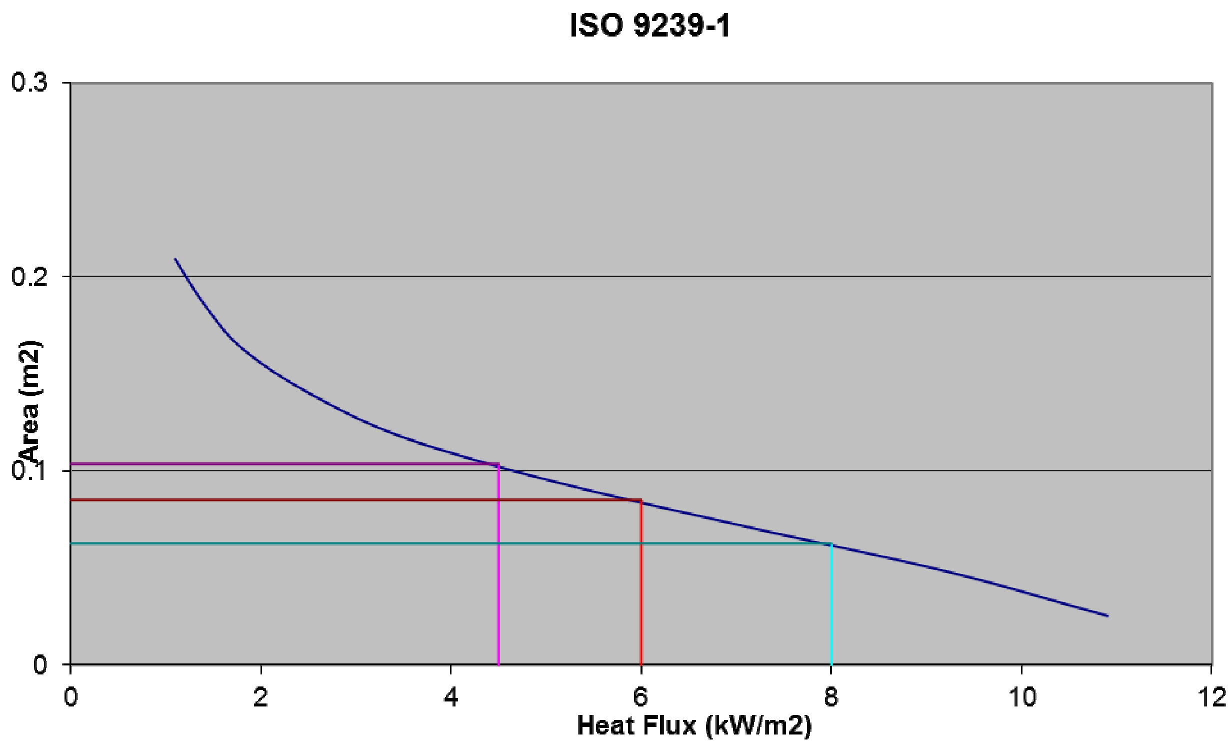


Table 7 – Use of ISO 9239-1 for determination of A_s for flooring composites

Critical Heat Flux (kWm^{-2})	Burnt area of test specimen (m^2)	Perceived burn area of flooring A_s (m^2)
8	0.0625	0.19
6	0.085	0.26
4.5	0.1035	0.31

It is proposed that Table 7 could be used to specify the perceived burn area A_s for floor composites when selecting the scaling factor to be used when calculating FED and FEC. For example, the following criteria for A_s could be considered for IN16 products in various operation categories of railway vehicle:-

HL1 $0.31m^2$
HL2 $0.26m^2$
HL3 $0.19m^2$

3.4 c) Additional data from ISO 5658-4 *'Vertical spread of flame'* tests confirms that there is a wide range of propensity for products to exhibit surface spread of flame (see Table 8). LSF have also re-examined flame propagation data from the EC ROLAND project (ref.30) where irradiance mapping of the critical surface flame spreads was measured versus time using a heat flux meter at every 100mm in three directions.

Table 8 – Flame spread results from ISO 5658-4 tests

Product	Burned area m^2	Lateral CFE kW/m^2	Upwards CFE kW/m^2	Downwards CFE kW/m^2
FR Chipboard 14mm	0,058	30,5	4,0	41,2
Gypsum board 12,5mm	0,018	30,5	15,6	41,2
PUR with Al foil glued on calcium silicate 40mm	0,078	30,5	3,4	41,2
PUR with paper glued on calcium silicate 40mm	1,200	2,1	2,6	9,7
XPS 40mm glued on calcium silicate	1,100	3,2	2,6	9,7
PVC 3mm	0,170	26,1	2,9	34,8
Layered polycarbonate 16mm	0,166	28,8	6,9	9,7
Massive timber varnished 10mm	1,175	2,1	2,6	9,7
FR Plywood 15mm	0,505	8,8	2,9	9,7
Standard Plywood 15mm	0,840	4,1	2,6	9,7
FR EPS 40mm	1,200	2,1	2,6	9,7
FR EPS 80mm	0,136	28,1	2,7	41,2
Wallpaper glued on gypsum board	0,265	9,7	11,7	12,0
Vinyl paper glued on gypsum board	0,280	9,7	9,1	12,0
PVC resilient glued on gypsum board	0,420	14,2	2,6	9,7

From the above results the following classifications may be proposed for lining products: -

- If the critical flux at extinguishment (CFE) is between 50 and 40 kW/m^2, the surface that will produce effluent is < 0,05 m^2
- If CFE is between 40 and 30 kW/m^2, the surface is approximately 0,1 m^2
- If CFE is between 30 and 20 kW/m^2, the surface is approximately 0,2 m^2

3.4 d) For many lining products (especially for walls and ceilings), the CFE flame spread requirements of CEN TS 45545-2 are readily satisfied (see Table 9). Hence, it may be proposed to CEN/TC256 that for lining products which can demonstrate a good CFE flame spread performance, there should be a less stringent area of perceived burning applied in the calculations of FED and FEC. Since wall and ceiling products may be exposed to type 2 ignition sources, the perceived area of the product burning A_s may be reduced from 0.7m^2 to 0.2m^2 if the lining product has a CFE $\geq$ 30 kW/m^2.

In the Task 6.5 studies, calculations of IN1 products have been conducted with both A_s criteria of 0.2m^2 and 0.7m^2 since no data was available from ISO 5658-2 or ISO 5658-4 tests on the specific products submitted for the TRANSFEU project. However, since ISO 5658-2 is already specified in EN 45545-2, the test data used in determining CFE may also be used to calculate A_s for the same product sectors.

Table 9 – Reaction to fire test results for wall and ceiling linings used in European railway vehicles (ref.25)

Product	Thickness (mm)	CFE (kW/m^2)	MARHE (kW/m^2)
FR Polyester GRP	3	41.3	86
Decorative laminate sandwich panel	15	30.3	68
NFR Polyester	4	7.7	136
Melamine/Phenolic formaldehyde laminate	3	33.0	56
FR Plywood	10	14.8	165
MF/Al honeycomb/MF sandwich panel	14.5	36.7	104
Painted PF GRP	4	30.7	34
Polyester ceiling carpet glued to 2mm Al sheet	2.5	30.8	32

3.4 e) For some product sectors, rule 3 may necessitate the use of other flame spread tests (such as the cable ladder test for cables and complete passenger seat test for upholstery). The A_s derivations should also be re-assessed in future for these product sectors. The real scale coach tests in Task 6 (Scenarios 2A and 2B) indicate that A_s should be $0.7m^2$ for product sector F1.

IV 3.5 Rule 4

In Task 6 of TRANSFEU, full-scale and real-scale railway vehicle tests were conducted. It is important therefore to consider the results of these tests so that the classification of various railway products can be considered in the context of their end-use applications. The input of observed burning areas from these validation studies has been considered with respect to the perceived burn areas of the 70 products that have been examined in Task 6.5.

For example, at the end of real-scale tests on double deck coaches in Italy, the wall and the ceiling showed limited burn damage. For both products of the first test (IN 1-10 ceiling; IN 1-5 side wall) and of the second test (IN 1-8-2 ceiling; IN 1-8-1 side wall), the burnt area (disregarding the thermal attack on the window) is less than $0.02m^2$ to the wall and practically zero with regard the part concerning the ceiling (2m from the floor), even though the fire model used is the ignition model 5, i.e. 75kW/150kW. The damaged areas of products exposed in double-deck coach tests in Italy are clearly visible in the photographs in Annexes A and B.

NB: When classifying a product for particular HL categories, other reaction to fire requirements (such as MARHE and CFE as detailed in EN 45545-2 for specific product sectors) shall also be satisfied.

Section V - Refinements to the classification criteria in Task 6.5

V.1 CEN TS 45545 Part 2 criteria based on maximum CIT

CEN TS 45545: Part 2 specifies different CIT values for products according to the hazard levels required in the railway vehicles. This approach is summarized in Table 10 below where the classification criteria for each HL category are prescribed maximum CIT values as measured at 4 minutes and 8 minutes in the ISO 5659-2 FTIR procedure.

Table 10 - Classification for toxicity of gaseous effluents based on CEN/TS 45545-2

Requirement	Product sectors	Maximum CIT		
		HL1	HL2	HL3
R1	IN1 IN8	1.2	0.9	0.75
R2	IN2	1.2	0.9	0.75
R3	IN3	1.2	0.9	0.75
R5	F1E	1.2	0.9	0.75
R6	IN6 EX1A	-	1.8	1.5
R9	IN16	1.2	0.9	0.75
R10	E4A	1.2	0.9	0.75
R14	E1A	1.2	0.9	0.75
R20	F1A	1.2	0.9	0.75
R21	F1B1	-	-	-

V.2 TRANSFEU WP3 criteria based on time to CIT = 1

A key objective of TRANSFEU WP3 was to devise a classification for products installed on railway vehicles that is based on the time to reach a critical limit, which is defined by the CIT as calculated from the continuous gas concentration time curves. The classification principles are explained in report WP3N37_D3.1P. The RSET for this purpose relates to the maximum time that passengers or crew have to escape from the coach that is impacted by the fire. They may escape to a safe place on the train (such as behind a fire barrier on OC3 trains) or evacuate outside with OC1 trains or to a station with OC2 and OC4 trains. The connection to the classification of reaction-to-fire performance may be met by use of a categorization approach for CIT as shown in Table 11.

Table 11 - Example of RSET classification criteria for toxicity of gas mixtures from fires on railway vehicles

Category	Level 1*	Level 2*
Time to CIT_G = 1	x minutes	y minutes

*These reaction to fire performance levels are related to the hazard levels (HL) as defined in CEN TS 45545-2 and the RSET classification criteria were initially agreed by rail vehicle operators. These levels, which were used in developing the TRANSFEU WP3.4, were essentially based on running capability concepts. The criteria adopted in the system of WP3.4 were as follows: -

For Operation Category 1 trains, the RSET (x) should be 2 minutes and to satisfy this requirement, the ASET (calculated as time to CIT = 1) should be greater than 2 minutes.

For Operation Category 2, 3 and 4 trains, the RSET (y) should be 4 minutes and to satisfy this requirement, the ASET (calculated as time to CIT = 1) should be greater than 4 minutes.

V.3 TRANSFEU WP6.5 refined criteria based on FED and FEC levels

The time to CIT = 1 is a pragmatic parameter that was used in WP3 to provide a critical criterion for passenger survivability based on concentrations of 8 common fire gases in a railway coach of 150m^3 volume. It is not toxicologically appropriate for determination of the Available Safe Escape Time according to the principles of ISO 13571, which is globally accepted as the most appropriate standard for determination of human tenability in the presence of toxic gases from fires in buildings and transport vehicles.

The use of FED/time and FEC/time graphs for classification of toxicity is outlined in Section III.5. The International Standard ISO 13571 states that the time to compromised tenability is the shortest of four distinct times estimated from consideration of asphyxiant fire gases, irritant fire gases, heat and visual obscuration due to smoke. In TRANSFEU WP6.5 it is the classification of the fire gases that has been addressed. In particular, we have noted the guidance that if escape to a place of refuge is to be considered, the time to compromised tenability may reasonably be equated to the available safe escape time (ASET).

The safety objectives of passengers and crew in railway vehicles have also been studied (6) in TRANSFEU WP4 so that a broader interpretation of RSET and ASET can be made based on key times in a fire event, i.e. ignition time, fire detection and alarm, braking time, evacuation time and running time (see Figure 4). As a result of these studies carried out by experienced railway operators and train builders, TRANSFEU WP6.5 can now propose improved performance criteria for the classification of toxicity of fire gases generated by products installed in European railway vehicles.

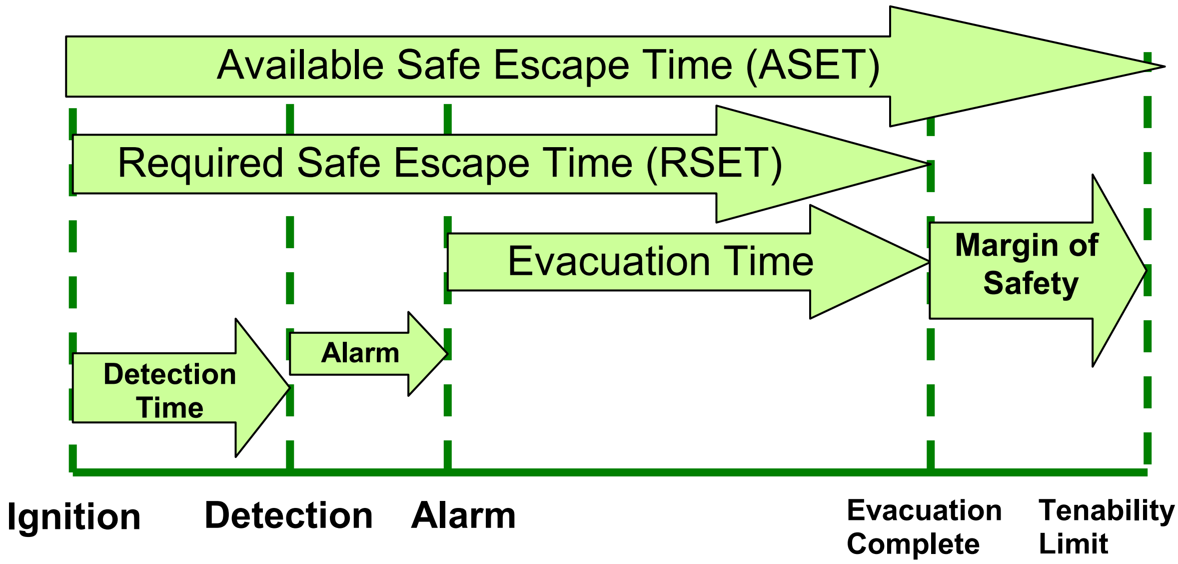
The required ASET times for the different categories of railway vehicle are summarized in Table 12. These values of required ASET will be used to refine the classification system initially proposed in TRANSFEU WP3.4.

NOTE – The times given in Table 12 are essentially Required Safe Escape Times (RSET). The ASET requirement for toxicity will be 'greater than (or equal) to these times' in classification tables for EN 45545-2.

Table 12 – Required ASET times for classification of fire effluents

Hazard Level of Railway Vehicle	ASET (minimum) in seconds	ASET (minimum) in minutes
HL1	270	4.5
HL2 (OC 2)	450	7.5
HL2 (OC3)	450	7.5
HL3	1200	20

Figure 4 – Schematic representation of times contributing to RSET and ASET in the event of a fire in a railway vehicle



V.4 Significance and use of FED and FEC threshold criteria

As indicated in Section III.4 'Margins of Safety', the choice of threshold values for FED and FEC will be a regulatory one dependant on the operating conditions and passenger profile on the train. ISO 13571 clauses 5 and A.5.2 clearly explain the significance of various threshold values of FED and FEC from 0.1 to 1.0. These clauses particularly point out the influence of the different values in terms of the times to compromised tenability of some susceptible subpopulations.

Examples of susceptibilities are statistically presented based on assumptions of a log-normal distribution of responses: -

- FED and/or FEC threshold criteria of 1.0 translate to 50.0% of the population being susceptible and therefore statistically estimated to experience compromised tenability, which would cause them difficulty to escape.
- FED and/or FEC threshold criteria of 0.3 translate to 11.4% of the population being susceptible and therefore statistically estimated to experience compromised tenability, which would cause them difficulty to escape.
- FED and/or FEC threshold criteria of 0.2 translate to 5.4% of the population being susceptible and therefore statistically estimated to experience compromised tenability, which would cause them difficulty to escape.
- FED and/or FEC threshold criteria of 0.1 translate to 1.1% of the population being susceptible and therefore statistically estimated to experience compromised tenability, which would cause them difficulty to escape.

Taking the time to compromised tenability as the measure of ASET, TRANSFEU WP6 decided that it is not appropriate for fire safety objectives to classify railway vehicle products using FED and/or FEC threshold criteria of 1.0.

The WP6 partners agreed that predictions of ASET should be done using FED and/or FEC threshold criteria of 0.3, 0.2 and 0.1. The consequences of this decision for classifications would be presented for all product sectors in a comparable way to the matrix of requirements as presented for a threshold of CIT = 1 in the TRANSFEU D3.4 report.

It should be noted that fire safety engineers are already using the principles of ISO 13571 and those of Purser (10) for predicting escape times of occupants from fires in buildings. Tenability times are often based on an FED threshold value of 0.3. An example of this FSE methodology applied to buildings is the BSI published document PD 7974 Part 6 (2004).

Section VI – Summary of validation studies of classification criteria for use in EN 45545-2

VI.1 One zone model

- Volume of both single deck and double deck vehicles is $150m^3$.
  The internal volumes were essentially similar in the real scale tests of a single deck coach in France and a double deck coach in Italy.
- For purposes of classification, there is only natural ventilation present.
  There was only natural ventilation in all real scale tests.

VI.2 Calculations of FED and FEC – Gas summation term

- The same 8 gases were considered in FED and FEC calculations as in CEN/TS45545-2 when calculating CIT. However, it was considered to be no longer valid to use the reference values of NIOSH. These have been replaced by the reference values that are given in ISO 13571 (2nd Edition; 2012) since both FED and FEC are more appropriately related to physiological and behavioural effects shown by exposed passengers and crew in railway vehicle fires.

- Whilst ISO 13571 recognizes that aldehydes (such as acrolein and formaldehyde) are irritant species in many combustion effluents, they were not detected in the real-scale tests. They were detected by some labs for certain products tested in ISO 5659-2/FTIR procedure. Hence, it is not considered to be valid to include acrolein and formaldehyde in calculations of FED and FEC based on small scale smoke chamber tests.

VI.3 Calculations of FED and FEC – Scaling factors

- The development of CEN/TS 45545-2 indicated that a scaling factor needed to be introduced to link the area of a test specimen burning in the ISO 5659-2 smoke chamber to that of a product perceived to burn in the model coach. This link has been pragmatically related to an estimated area of the product perceived to burn when it is exposed to a real ignition source (such as rolled-up newspaper or a piece of luggage). The same approach has been taken when calculating FED and FEC. This concept is described in EN 45545-2 Annex C.16 as 'the area of a product that is perceived to burn in the fire model used for CIT calculations'.

- Whilst CEN/TS 45545-1 provides some information on the area of product exposure that might occur with ignition models 1, 2, 3, 4 and 5, the calculations of CIT were all conducted with A_s equal to $0.1m^2$. This assumption is not considered to be valid and more relevant values for A_s have been used when calculating FED and FEC. These values were selected based on an assessment of real product sectors and on test data derived from both full-scale (e.g. seats, wall/ceiling linings and cables) and on the real-scale coach tests. Some further observed data on damage assessments and post-test photographs from TRANSFEU WP6.3 full-scale coach tests of seats and wall panels may be consulted in references 17 and 18.

- It should be noted that the A_s values selected are product specific (i.e. all the products in a classification product sector such as IN 1 wall linings) are calculated with the same assumed A_s (such as $0.7m^2$ for the IN 1 product sector). This A_s contribution to the scaling factor calculation for wall linings is well characterised from full-scale tests using ignition model 5 [ref. Annex C] and is essentially confirmed by real-scale tests.

- The main influence of A_s in the early growth stage of a fire is likely to be the surface area of the product that is heated by the ignition model. Hence, for wall linings where a worst case scenario of a corner fire should be considered, the assumptions of EN 45545-1 concerning the perceived surface area of wall likely to burn are broadly correct and should be maintained in further development of this classification methodology.

- Whilst the TRANSFEU approach is considered to be more valid than that of CEN/TS 45545-2, there are some concerns about categorizing all the products in a product sector with the same A_s value and this assumption needs to be checked further for products with significantly different flame spread propensities [see Section IV 3.4]. Further consideration should be given to inclusion of a flame spread parameter in calculating the scaling factor for large area products such as walls, ceilings and floor composites.

- Some caution should be exercised in deriving scaling factors from real-scale tests where multi-product assemblies are being evaluated. Assumptions about individual product contributions will probably be flawed and more confident predictions are likely from single product full-scale tests.

VI.4 FED/time curves and FEC/time curves

- The calculations of CIT according to CEN/TS 45545-2 and prEN 45545-2 are only possible at 4 minutes and 8 minutes due the small amount of gas data acquired in the specified procedure. This is a serious limitation of the current TS and proposed EN (1st edition). One reason for this limitation is that real gas/time data may not be suitably characterized by the test data at only 2 points in time. It is possible to miss peaks occurring between 4 and 8 minutes or in some situations to miss a continued build-up of gases after 8 minutes or a decrease of some gases with time after 8 minutes.
- The continuous measurement of combustion gases over a 20 minute period that occurs in the TRANSFEU WP2 procedure enables a much more valid assessment of the potential toxicity of the mixture of gases to be done. Hence, the determination of both FED/time and FEC/time curves provides realistic time-data for decisions about the compromised tenability time of passengers and crew in various operation categories of railway vehicles.

VI.5 Derivations of ASET

- There is no link between escape times and time to CIT = 1 as advocated in CEN/TS 45545-2 and prEN 45545-2. The criteria chosen are solely based on old assumptions of gas concentrations from NIOSH reference concentrations.

- The initial proposal of TRANSFEU to CEN/CENELEC JWG in 2011 was a significant step forward based on continuous analysis of CIT/time measurements. However, the validity of this approach would still be in doubt and not relatable to the time to compromised tenability offered by the guidance in ISO 13571.

- It is the opinion of the toxicity experts globally who have produced ISO 13571 that the time to compromised tenability may justifiably be equated to ASET for fire zones (such as railway coaches). Hence, it is more valid to determine and correctly analyse FED/time and FEC/time curves for products as installed in a train than to rely on old prescribed CIT values.

VI.6 Required ASET for different operation categories of railway vehicle

- There is no direct link between toxicity thresholds for maximum allowable CIT values obtained from railway materials and various operation categories of train. The link is a tenuous assumption to require lower CIT maxima for higher risk railway vehicles. There does not appear to be any supporting research that justifies the selection of the CIT values and their specification associated with HL1, HL2 or HL3.

- Based on wide practical experience, the railway partners of TRANSFEU have assessed all the required train operating scenarios in Europe and concluded that the safety objectives of passengers and crew can be satisfied by specifying carefully calculated required ASET times. This fire safety engineering approach takes into account the time of detection of an ignited item and the alarm time, the braking time and running time, and the evacuation time plus a margin of safety.

- With the above FSE approach, European train operators and builders can validate the toxicity of products according to the operation categories of the railway vehicles. Required ASET times can then be confidently assigned to HL1, HL2 and HL3 vehicles.

- In EN 45545-2 Annex C.16, calculations of CIT have a specific meaning for specific materials/ items, i.e.
    - General products are designated as CIT_G
    - Non-listed products are designated as CIT_{NLP}
    - Cables are designated as CIT_C

  In this report, the ASET times from TRANSFEU WP6.5 calculations that are proposed for refinement of the EN 45545-2 product classification system are similarly designated; i.e.
    - General products as $ASET_G$
    - Non-listed products as $ASET_{NLP}$
    - Cables as $ASET_C$

VI.7 Safety margins

- The toxicity criteria used in CEN/TS 45545-2 and prEN 45545-2 does not allow an informed safety margin to be applied in product classifications for railway vehicles.

- The ISO 13571 system that is recommended by TRANSFEU provides an opportunity for regulators to consider the needs of susceptible subpopulations (especially young children, the elderly and asthmatic adults). ASET calculations have been conducted for FED and FEC thresholds of 0.1, 0.2 and 0.3. This data base on 70 products will provide valid information for future specifiers of railway vehicles. By applying a similar FSE approach to other surface transport (especially marine vessels and high occupancy road transport), specifiers will also be able to define appropriate safety margins for their applications.

- Another design issue for train builders is to recognize that the toxicity classifications derived from ASET calculations are product specific according to the philosophy of EN 45545-2. Hence, the calculations of FED and FEC are performed with appropriate assumptions (such as perceived area burning) that apply to the type and location of

the product being classified. However, in reality a rail vehicle is a complex assembly of individual different products and if a fire event occurs, that fire will probably not be limited to an attack on only one single product. For this reason, it may be necessary to devise an additional safety margin for assemblies of products to better approach reality.
For example, if the threshold criteria for FED and FEC equal 0.3 and if adjacent products (such as a seat and wall lining) both individually satisfy that requirement with FED/FEC of 0.2, the rail vehicle might be assumed to be toxicologically safe. But in reality, passenger tenability in a fire could be compromised since FED/FEC of the 2 products combined would be 0.4.

Section VII - Results of ASET determinations on lining products

VII.1 Comparison of classification parameters

For both the CEN/TS 45545-2 and TRANSFEU WP6.5 calculations of toxicity parameters, the volume of the coach V_{coach} is 150m^3 and the ventilation Q_{air} to the coach is 0m^3/s. The calculations of both systems are based on the reference concentrations of the same 8 gases. For CEN/TS 45545-2, these concentrations are specified in CEN/TS 45545-2 Table 1 and for TRANSFEU D6.5 they are specified in ISO 13571. The scaling factor includes the surface area A_s of the product that is perceived to burn. This area is specified for each product sector based on research experience of fires caused by ignition models 1 to 4 (Type 1) fires and ignition model 5 (Type 2) fires.

Table 13A - Comparison of classification parameters specified in CEN TS45545-2 with those proposed in TRANSFEU WP6.5 on ASET for interior lining products

	CEN TS 45545-2 specification based on claimed (or determined) reaction to fire performance level (HL)					EN 45545-2 proposal from TRANSFEU WP6.5 results	
Product	HL	Perceived burn area m^2	CIT mean at 4 mins	CIT mean at 8 mins	Toxicity Requirement in Table 7 Max CIT mean	Perceived burn area m^2	$ASET_{mean}$ derived from times for FED/FEC = 0.3 minutes
IN1-2	3	0.1	0	0	0.75	0.2 0.7	> 20 > 20
IN1-3	3	0.1	0.08	0.15	0.75	0.7	5.25
IN1-4	3	0.1	0.54	1.52	0.75	0.2 0.7	19.30 5.25
IN1-5	2	0.1	0.02	0.06	0.9	0.2 0.7	> 20 17.42
IN1-7	2	0.1	0.10	0.21	0.9	0.2 0.7	> 20 11.58
IN1-8-1	2	0.1	0.06	0.14	0.9	0.2 0.7	> 20 > 20
IN1-8-2	2	0.1	-	-	0.9	0.2 0.7	> 20 18.58
IN1-10	1	0.1	0.082	0.175	1.2	0.2 0.7	19.75 9.58

Key: Green highlight indicates toxicity pass for the HL category of the product shown in column 2.
Red highlight indicates a toxicity fail for the HL category of the product shown in column 2

Table 13B - Comparison of classification parameters specified in CEN TS45545-2 with those proposed in TRANSFEU WP6.5 on ASET for other interior products

Product	HL	Perceived burn area m^2	CIT mean at 4 mins	CIT mean at 8 mins	Toxicity Requirement in Table 7 Max CIT	Perceived burn area m^2	$ASET_{mean}$ derived from times for FED/FEC = 0.3 minutes
	CEN TS 45545-2 specification based on claimed (or determined) reaction to fire performance level (HL)					EN 45545-2 proposal from TRANSFEU WP6.5 results	
IN3-2	1	0.1	0.04	0.23	1.2	0.2	> 20
IN6-1	1	0.1	2.52	2.23	No requirement	0.7	0.50
IN6-3	3	0.1	0.02	0.03	No requirement	0.7	> 20
IN10A-1	2	0.1	0.13	0.24	0.9	0.2	> 20
IN10A-2	3	0.1	0	0.04	0.75	0.2	> 20
IN10A-3	1	0.1	0.14	0.21	1.2	0.2	> 20
IN12-1	1	0.1	0.25	0.42	1.2	0.7	4.25
IN12-2	2	0.1	0.17	0.22	0.9	0.7	18.42
IN12-3	3	0.1	0	0	0.75	0.7	> 20
IN16-2	3	0.1	0	0.01	0.75	0.1	> 20
IN16-3	2	0.1	0.15	0.33	0.9	0.1	> 20
IN16-4	1	0.1	0.31	0.54	1.2	0.1	> 20
IN16-5	2	0.1	0.36	0.53	0.9	0.1	> 20
IN14-1	2	0.1	0	0.01	0.9	0.1	> 20

Key:
Green highlight indicates toxicity pass for the HL category of the product shown in column 2.
Red highlight indicates a toxicity fail for the HL category of the product shown in column 2.

Table 13C - Comparison of classification parameters specified in CEN TS45545-2 with those proposed in TRANSFEU WP6.5 on ASET for exterior products

	CEN TS 45545-2 specification based on claimed (or determined) reaction to fire performance level (HL)					EN 45545-2 proposal from TRANSFEU WP6.5 results	
Product	HL	Perceived burn area m^2	CIT mean at 4 mins	CIT mean at 8 mins	Toxicity Requirement in Table 7 Max CIT	Perceived burn area m^2	$ASET_{mean}$ derived from times for FED/FEC = 0.3 minutes
EX1A-1	2	0.1	0.01	0.02	1.8	0.7	> 20
EX1A-2	2	0.1	-	-	1.8	0.7	> 20
EX1A-3	3	0.1	0.002	0.04	1.5	0.7	> 20
EX1B-1	2	0.1	0.32	0.95	1.8	0.7	5.25
EX3-1	3	0.1	0.02	0.05	1.5	0.7	18.83

Key:
Green highlight indicates toxicity pass for the HL category of the product shown in column 2.
Red highlight indicates a toxicity fail for the HL category of the product shown in column 2.

Section VIII - Results of ASET determinations on seats and furnishing products

VIII.1 Comparison of classification parameters

For both the CEN/TS 45545-2 and TRANSFEU WP6.5 calculations of toxicity parameters, the volume of the coach V_{coach} is $150m^3$ and the ventilation Q_{air} to the coach is $0m^3/s$. The calculations of both systems are based on the reference concentrations of the same 8 gases. For CEN/TS 45545-2, these concentrations are specified in CEN/TS 45545-2 Table 1 and for TRANSFEU WP6.5 they are specified in ISO 13571. The scaling factor includes the surface area A_s of the product that is perceived to burn. This area is specified for each product sector based on research experience of fires caused by ignition models 1 to 4 (Type 1) fires and ignition model 5 (Type 2) fires.

Table 13D - Comparison of toxicity classification parameters specified in CEN/ TS45545-2 with those proposed in TRANSFEU WP6.5 on ASET for seats and furnishing products

	CEN TS 45545-2 specification based on claimed (or determined) reaction to fire performance level (HL)					EN 45545-2 proposal from TRANSFEU WP6.5 results	
Product	HL	Perceived burn area m^2	CIT mean at 4 mins	CIT mean at 8 mins	Toxicity Requirement in Table 7 Max CIT	Perceived burn area m^2	$ASET_{mean}$ derived from times for FED/FEC = 0.3 mins
IN8-1	1	0.1	0.30	0.38	1.2	0.7	0.75
IN8-2	2	0.1	0.03	0.03	0.9	0.7	> 20
IN8-3	3	0.1	0.003	0.009	0.75	0.7	> 20
F1A-1-2	2	0.1	0.13	0.23	0.9	0.2 0.7	> 20 > 20
F1A-1-3	3	0.1	0.19	0.28	0.75	0.2 0.7	> 20 5.42
F1A-1-4	2	0.1	0.32	0.39	0.9	0.2 0.7	> 20 1.00
F1A-2-1	2	0.1	0.21	0.27	0.9	0.2 0.7	> 20 > 20
F1A-2-4	2	0.1	0.12	0.15	0.9	0.2 0.7	> 20 > 20
F1B-2	1	0.1	0.16	0.30	n/r	0.1	> 20
F1E-1	2	0.1	0.09	0.53	0.9	0.1	> 20
F3-1	3	0.1	0.09	0.10	0.75	0.7	> 20
F5-1	3	0.1	0.01	0.01	0.75	0.7	> 20

Key:
Green highlight indicates toxicity pass for the HL category of the product shown in column 2.
Red highlight indicates a toxicity fail for the HL category of the product shown in column 2.

Section IX Results of ASET determinations on cables, limited surfaces, electro-technical and non-listed products

IX.1 Comparison of classification parameters

For both the CEN/TS 45545-2 and TRANSFEU WP6.5 calculations of toxicity parameters, the volume of the coach V_{coach} is 150m^3 and the ventilation Q_{air} to the coach is 0m^3/s. The calculations of both systems are based on the reference concentrations of the same 8 gases. For TS 45545-2, these concentrations are specified in TS 45545-2 Table 1 and for TRANSFEU WP6.5, they are specified in ISO 13571. The scaling factor includes the surface area of the product A_s that is perceived to burn. This area is specified for each product sector based on research experience of fires caused by ignition models 1 to 4 (Type 1) fires and ignition model 5 (Type 2) fires.

Table 13E - Comparison of classification parameters specified in CEN /TS45545-2 with those proposed in TRANSFEU WP6.5 on ASET for electrotechnical, limited surfaces and non-listed products

Product	CEN /TS 45545-2 specification based on claimed (or determined) reaction to fire performance level (HL)					EN 45545-2 proposal from TRANSFEU WP6.5 results	
	HL	Model*	CIT mean at 4 min	CIT mean at 8 min	Toxicity requirement in Table 7 Max CIT	Burn area (or weight) (m^2)	$ASET_{mean}$ derived from times for FED/FEC = 0.3 (minutes)
E2A-1	3	Not applicable - Products were not tested according to NF X70-100-1 and 2 in the TRANSFEU project			0.75	0.2	>20
E2A-2	2				0.9	0.2	3.75
E4A-1	2				0.9	0.1	> 20
E7A-1	3				0.75	0.1	>20
E7A-2	2				0.9	0.1	>20
NL-1	3				0.75	512g	> 20
NL-2-3	1				1.2	300g	>20

Key:
Green: toxicity pass for the HL category of the product shown in column 2.
Red: toxicity fail for the HL category of the product shown in column 2.

* The CIT in CEN/TS 45545-2 is based on the NF X70-100-1 and -2 test for E2A and E7A where R23 is deemed to apply for these specific products (refer to Table 11 of CEN/TS 45545-2).

Table 13F - Comparison of classification parameters specified in CEN/ TS45545-2 *with those proposed in TRANSFEU WP6.5 on ASET for cables*

Product	CEN/ TS 45545-2 specification based on claimed (or determined) reaction to fire performance level (HL)					EN 45545-2 proposal from TRANSFEU WP6.5 results	
	HL	Model	CIT mean at 4 min	CIT mean at 8 min	Toxicity requirement in Table 7 Max CIT	Burn area	$ASET_{mean}$ derived from times for FED/FEC = 0.3 (minutes)
E1A-1-1	3	Not applicable Products were not tested according to NF X70-100-1 and 2 in the TRANSFEU project.			0.75	As in test.	>20
E1A-1-2	3				0.75		>20
E1A-1-3	3				0.75		>20
E1A-1-4	3				0.75		>20
E1A-1-5	3				0.75		>20
E1A-1-6	3				0.75		>20
E1A-1-7	3				0.75		>20
E1A-1-8	3				0.75		>20

Section X ASET Rankings of Step1 Products

Table 14 – ASET ranking of 16 products according to TRANSFEU D3.4 and D6.5 systems

Product	D3.4		D6.5	
	Time to CIT = 1 (minutes)	Ranking	Time to FED/FEC =0.3 (minutes)	Ranking
IN1-10	>20	1	9.58	4
IN10A-1	>20	1	>20	1
IN10A-2	>20	1	>20	1
F1A-1-1	>20	1	>20	1
F1A-1-2	>20	1	>20	1
F1A-1-3	>20	1	>20	1
F1A-2-2	>20	1	>20	1
IN8-1	>20	1	<1	5
IN8-3	>20	1	>20	1
IN16-1	>20	1	>20	1
IN16-3	>20	1	>20	1
IN16-6	>20	1	>20	1
IN1-5	11.75	2	17.42	2
IN1-8-1	8.25	3	>20	1
IN1-7	5.42	4	11.58	3
IN3-1	3.0	5	17.42	2

Section XI - Classifications of railway products using ASET system for Task 6.5

XI.1 Essential objectives of the classification system

The essential requirements for the fire behaviour of materials and components installed in railway vehicles are defined in EN 45545-2 clause 4 and the specifications are shown in Tables 2 and 5. The requirements for listed products are assigned R numbers in Table 2 and the set of reaction to fire parameters required to define the HL performance of a product are detailed in Table 5. These prescriptive requirements are based on test results from flame spread, heat release and smoke opacity data obtained from standard tests carried out under laboratory conditions that simulate the realistic end-use installation of the product on a railway vehicle. The requirements for toxicity of fire effluents from these listed products are based on CIT test data obtained from single point sampling of the gases at 4 minutes and 8 minutes in the EN ISO 5659-2 smoke chamber (Tests 11.01 or 11.02). Alternatively, for certain products (such as cables, small electrotechnical and minor non-listed products), test data from the NF X70-100-2 tube furnace (Test T12) is permitted.

In the following sections, the recommendations for determining ASET for burning products are tabulated with the prescribed EN 45545-2 requirements for all the product sectors examined in TRANSFEU WP6.5. The required threshold limits for FED and FEC have been assumed to be 0.3. However, this value is considered for comparative purposes in this report and it should be understood that other threshold values may be specified, such as 0.2 (or 0.1 for high risk scenarios).

In addition, no considerations have been applied to changes in the flame spread, heat release or optical density specifications for listed products in the TRANSFEU programme. However, there is strong support for a more relevant method for classification of the toxicity of fire effluents for use when determining the HL performance requirements of listed products. This validated method is now available for incorporation into EN 45545-2 by combining the EN ISO 5659-2 smoke chamber measurements with continuous analysis of combustion gases using FTIR spectrometry.

XI.2 R1 set of requirements for IN1, IN8 and IN12 product sectors in EN 45545-2

Product Description	Test Method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
a) **IN1** Wall and ceiling linings b) **IN8** Curtains and sun blinds c) **IN12** Interior surface of air ducts	T02 ISO 5658-2	CFE kWm^{-2}	Minimum	20 [a]	20 [a]	20 [a]
	T03.01 ISO 5660-1 : $50kWm^{-2}$	MARHE kWm^{-2}	Maximum	[a]	90	60
	T10.01 EN ISO 5659-2: $50kWm^{-2}$	$D_s(4)$ dimensionless	Maximum	600	300	150
	T10.02 EN ISO 5659-2: $50kWm^{-2}$	VOF4 Minutes	Maximum	1200	600	300
	T11.01 EN ISO 5659-2: $50kWm^{-2}$	CIT_G dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: $50kWm^{-2}$ with continuous FTIR analysis; A_S= $0.7m^2$	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*TRANSFEU WP2 proposal to replace the T11.01 test and gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
IN1	IN1-2 IN1-3 IN1-5 IN1-7 IN1-8 IN1-10	IN1-4	IN1-2 IN1-5 IN1-7 IN1-8-1 IN1-8-2 IN1-10	IN1-3 IN1-4
IN8	IN8-1 IN8-2 IN8-3		IN8-2 IN8-3	1N8-1
IN12	IN12-1 IN12-2 IN12-3		IN12-2 IN12-3	IN12-1

XI.3 R2 set of requirements for IN2 and IN10A product sectors in EN 45545-2

Product Description	Test Method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
a) **IN2** Limited surfaces b) **IN10A** Upper surfaces of tables and toilet basins	T02 ISO 5658-2	CFE kWm^{-2}	Minimum	13 [a]	13 [a]	13 [a]
	T03.01 ISO 5660-1 : $50kWm^{-2}$	MARHE kWm^{-2}	Maximum	[a]	[a]	90
	T10.01 EN ISO 5659-2: $50kWm^{-2}$	$D_s(4)$ dimensionless	Maximum	600	300	150
	T10.02 EN ISO 5659-2: $50kWm^{-2}$	VOF4 Minutes	Maximum	1200	600	300
	T11.01 EN ISO 5659-2: $50kWm^{-2}$	CIT_G dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: $50kWm^{-2}$ with continuous FTIR analysis; A_s= $0.2m^2$	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.01 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
IN2	IN2-3	IN2-2	IN2-2 IN2-3	
IN10A	IN10A-1 IN10A-2 IN10A-3		IN10A-1 IN10A-2 IN10A-3	

XI.4 R3 set of requirements for IN3 product sector in EN 45545-2

Product Description	Test Method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
IN3 Strips and Light Diffusers	T02 ISO 5658-2	CFE kWm^{-2}	Minimum	13 [a]	13 [a]	13 [a]
	T03.01 ISO 5660-1 : $50kWm^{-2}$	MARHE kWm^{-2}	Maximum	[a]	[a]	[2)]
	T10.01 EN ISO 5659-2: $50kWm^{-2}$	$D_s(4)$ dimensionless	Maximum	600	480	240
	T10.02 EN ISO 5659-2: $50kWm^{-2}$	VOF4 Minutes	Maximum	1200	960	480
	T11.01 EN ISO 5659-2: $50kWm^{-2}$	CIT_G dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: $50kWm^{-2}$ with continuous FTIR analysis; A_s=0.2m^2	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.01 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
IN3	IN3-2	IN3-1	IN3-1 IN3-2	

XI.5 R4 set of requirements for IN14 product sector in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
IN14 Air filter materials	T05 EN ISO 11925-2 30s Flame Application	Flame Spread mm	Maximum	150 (within 60 s)	150 (within 60 s)	150 (within 60 s)
	T03.02 ISO 5660-1 : $25kWm^{-2}$	MARHE kWm^{-2}	Maximum	50	50	50
	T10.03 EN ISO 5659-2: $25kWm^{-2}$	D_s max dimensionless	Maximum	300	250	200
	T11.02 EN ISO 5659-2: $25kWm^{-2}$	CIT_G dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: $50kWm^{-2}$ with continuous FTIR analysis; A_S=0.1m^2	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.02 test and single point gas analysis procedure indicated in purple

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
IN14	IN14-1		IN14-1	

XI.6 R5 set of requirements for F1E product sector in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
F1E Back or base shell of passenger seat	T03.01 ISO 5660-1 : 50kWm^{-2}	MARHE kWm^{-2} +Integrity	Maximum No holes	90	90	60
	T10.01 EN ISO 5659-2: 50kWm^{-2}	$D_s(4)$ dimensionless	Maximum	600	300	150
	T10.02 EN ISO 5659-2: 50kWm^{-2}	VOF4 Minutes	Maximum	1200	600	300
	T11.01 EN ISO 5659-2: 50kWm^{-2}	CIT_G dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: 50kWm^{-2} with continuous FTIR analysis; A_s=0.1m^2/0.7m^2 (seat base) or A_s=0.1m^2/ 0.7m^2 (seat back) **	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.02 test and single point gas analysis procedure indicated in purple.
**The surface choice has to be in accordance with EN 50553 (Running Capability) and the design of the seat.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
F1E Base shell	F1E-1		F1E-1	
F1E Back shell		F1E-2	F1E-2	

XI.7 R6 set of requirements for IN6B, EX1A and EX3 product sectors in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
a) **IN6** Interior surface of gangways (if there is a fire barrier) b) **EX1A** External body shell (walls and windows) c) **EX3** External body shell (under frame)	T02 ISO 5658-2	CFE kWm^{-2}	Minimum	20[a]	20[a]	20[a]
	T03.01 ISO 5660-1 : $50kWm^{-2}$	MARHE kWm^{-2}	Maximum	[a]	90	60
	T10.04 EN ISO 5659-2: $50kWm^{-2}$	D_s max dimensionless	Maximum	-	600	300
	T11.01 EN ISO 5659-2: $50kWm^{-2}$	CIT_G dimensionless	Maximum	-	1.8	1.5
	*D2.1.3 EN ISO 5659-2: $50kWm^{-2}$ with continuous FTIR analysis: A_s=0.7m^2	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.02 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
IN6	IN6-1 IN6-2 IN6-3		IN6-3	IN6-1 IN6-2
EX1A	EX1A-1 EX1A-3		EX1A-1 EX1A-2 EX1A-3	
EX3	EX3-1			EX3-1

XI.8 R9 set of requirements for IN16 product sector in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
IN16 Floor composites	T04 EN ISO 9239-1	CHF kWm^{-2}	Minimum	4.5	6	8
	T03.02 ISO 5660-1 : $25kWm^{-2}$	MARHE kWm^{-2}	Maximum	-	50	50
	T10.03 EN ISO 5659-2: $25kWm^{-2}$	D_s max dimensionless	Maximum	600	300	150
	T11.02 EN ISO 5659-2: $25kWm^{-2}$	CIT_G dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: $25kWm^{-2}$ with continuous FTIR analysis: $A_s=0.1m^2$	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.02 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum Product passes	 Product fails	TRANSFEU WP6.5 ASET from FED/FEC = 0.3 Product passes	 Product fails
IN16	IN16-1		IN16-1	
	IN16-2		IN16-2	
	IN16-3		IN16-3	
	IN16-4		IN16-4	
	IN16-5		IN16-5	
	IN16-6		IN16-6	

XI.9 R10 set of requirements for E4A product sector in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
E4A Arc resistant insulation materials Type A	T02 ISO 5658-2	CFE kWm^{-2}	Minimum	30 [a]	30 [a]	30 [a]
	T03.01 ISO 5660-1 : $50kWm^{-2}$	MARHE kWm^{-2}	Maximum	90	90	60
	T10.01 EN ISO 5659-2: $50kWm^{-2}$	$D_s(4)$ dimensionless	Maximum	600	300	150
	T10.02 EN ISO 5659-2: $50kWm^{-2}$	VOF4 Minutes	Maximum	1200	600	300
	T11.01 EN ISO 5659-2: $50kWm^{-2}$	CIT_G dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: $50kWm^{-2}$ with continuous FTIR analysis; $A_S=0.1m^2$	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.02 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G Product passes	Product fails	TRANSFEU WP6.5 ASET from FED/FEC = 0.3 Product passes	Product fails
E4A	E4A-1		E4A-1	

XI.10 R14 set of requirements for E1A product sector in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
E1A Cables for interior uses (including power cables and control/ communication cables)	T09.1 EN 50265-2-1	Unburnt length mm	Minimum	Burned part ≤ 540 and un-burned part > 50	Burned part ≤ 540 and un-burned part > 50	Burned part ≤ 540 and un-burned part > 50
	T09.2 EN 50266-2-4	m	Maximum	2.5	2.5	2.5
	T09.3 EN 50305 clause 9.1.1	m	Maximum	2.5	2.5	2.5
	T09.4 EN 50305 clause 9.1.2	m	Maximum	1.5	1.5	1.5
	T13 EN 50268-2	Transmission %	Minimum	25	50	70
	T12 NF X 70-100-1&2 600°C	CITc Dimensionless	Maximum	1.2	0.9	0.75
	*prEN50399 with continuous FTIR analysis	$ASET_C$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T12 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_C Product passes*	Product fails	TRANSFEU WP6.5 ASET from FED/FEC = 0.3 Product passes	Product fails
E1A	E1A-1-1		E1A-1-1	
	E1A-1-2		E1A-1-2	
	E1A-1-3		E1A-1-3	
	E1A-1-4		E1A-1-4	
	E1A-1-5		E1A-1-5	
	E1A-1-6		E1A-1-6	
	E1A-1-7		E1A-1-7	
	E1A-1-8		E1A-1-8	
	E1A-2-1		E1A-2-1	
	E1A-2-2		E1A-2-2	
	E1A-2-3		E1A-2-3	

* Results provided by cable suppliers.

XI.11 R16 set of requirements for EX1B product sector in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
EX1B External cab housing	T02 ISO 5658-2	CFE kWm^{-2}	Minimum	13 [a]	13 [a]	13 [a]
	T03.01 ISO 5660-1 : $50kWm^{-2}$	MARHE kWm^{-2}	Maximum	[a]	90	60
	T10.04 EN ISO 5659-2: $50kWm^{-2}$	D_s max dimensionless	Maximum	-	600	300
	T11.01 EN ISO 5659-2: $50kWm^{-2}$	CIT_G dimensionless	Maximum	-	1.8	1.5
	*D2.1.3 EN ISO 5659-2: $50kWm^{-2}$ with continuous FTIR analysis: A_s=$0.1m^2$	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.02 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
EX1B	EX1B-1			EX1B-1

XI.12 R19 set of requirements for F5 product sector in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
F5 Bed clothes for couchettes and beds (including blankets, duvets, sleeping bags and pillows)	T07 EN ISO 12952-3/4	After burning time (sec)	Maximum	10	10	10
	T03.02 ISO 5660-1 : 25kWm^{-2}	MARHE kWm^{-2}	Maximum	50	50	50
	T10.03 EN ISO 5659-2: 25kWm^{-2}	D_s max dimensionless	Maximum	200	200	200
	T11.02 EN ISO 5659-2: 25kWm^{-2}	CIT_G dimensionless	Maximum	0.75	0.75	0.75
	*D2.1.3 EN ISO 5659-2: 25kWm^{-2} with continuous FTIR analysis: A_s=0.7m^2	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.02 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
F5	F5-1		F5-1	

XI.13 R20 set of requirements for F1A and F3 product sectors in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
F1A Upholstery for passenger seats and **F3** Mattresses	T03.02 ISO 5660-1 : $25kWm^{-2}$	MARHE kWm^{-2}	Maximum	75	50	50
	T10.03 EN ISO 5659-2: $25kWm^{-2}$	D_s max dimensionless	Maximum	300	300	200
	T11.02 EN ISO 5659-2: $25kWm^{-2}$	CIT_G dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: $25kWm^{-2}$ with continuous FTIR analysis; A_s=0.7m^2	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T11.02 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT_G maximum: Product passes	Product fails	TRANSFEU WP6.5 ASET from FED/FEC = 0.3: Product passes	Product fails
F1A	F1A-1-1 F1A-1-2 F1A-1-3 F1A-1-4 F1A-2-1 F1A-2-2 F1A-2-4		F1A-1-2 F1A-2-1 F1A-2-2 F1A-2-4	F1A-1-1 F1A-1-3 F1A-1-4
F3	F3-1		F3-1	

XI.14 R21 set of requirements for F1B product sector in EN 45545-2

Product Description	Test method Reference	Parameter Unit	Requirement Definition	HL1	HL2	HL3
F1B Armrests for passenger seats (upwards facing surfaces}	T03.02 ISO 5660-1 : $25 kWm^{-2}$	MARHE kWm^{-2}	Maximum	75	50	50
	*D2.1.3 EN ISO 5659-2: $50 kWm^{-2}$ with continuous FTIR analysis; A_s=$0.1 m^2$	$ASET_G$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

NOTE: There is no toxicity requirement for arm rests in CEN/TS 45545-2
*Proposal to introduce D2.1.3 test and single point gas analysis procedure indicated in yellow.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2		TRANSFEU WP6.5 ASET from FED/FEC = 0.3	
	Product passes	Product fails	Product passes	Product fails
F1B	F1B-1		F1B-1	
	F1B-2		F1B-2	

XI.15 R23 set of requirements for E2A, E7A and NL product sectors in EN 45545-2

Product Description	Test method Reference	Parameter and Units	Requirement Definition	HL1	HL2	HL3
a) **E2A** Cable containment (linear, interior) b) **E7A** Supply line system and high power devices (interior) c) **NL** Non listed product (interior).	T01 EN ISO 4589-2 : OI	Oxygen content %	Minimum	28	28	32
	T10.03 EN ISO 5659-2: $25kWm^{-2}$	D_smax Dimensionless	Maximum	600	300	150
	T12 NF X 70-100-1&2 800°C	CIT_{NLP} Dimensionless	Maximum	1.2	0.9	0.75
	*D2.1.3 EN ISO 5659-2: $25kWm^{-2}$ with continuous FTIR analysis; a) A_s=0.2m^2 b) A_s=0.1m^2 c) Defined by w_a and w_s	$ASET_{NLP}$ Time to FED and FEC = 0.3 Minutes	Minimum	4.5	7.5	20

*New proposal to replace the T12 test and single point gas analysis procedure indicated in purple.

Comparison of toxicity assessments for present CEN/TS 45545-2 method compared to proposed EN 45545-2 method developed in TRANSFEU project: -

Product sector	CEN/TS 45545-2 Prescribed CIT Product passes	Product fails	TRANSFEU WP6.5 ASET from FED/FEC = 0.3 Product passes	Product fails
E2A			E2A-1	E2A-2
E7A	Not applicable. Products not tested to NF X70-100-1 and 2 test		E7A-2	
NL			NL2-1	
			NL2-2	

Section XII - Conclusions and recommendations

1. The testing and continuous gas analysis of 70 train products has been completed. The results of the toxicity classifications based on ASET using time to FED = 0.3 and FEC = 0.3 as the failure criteria have been compared with the prescribed CEN/TS 45545-2 classifications based on CIT values determined at 4 minutes and 8 minutes during the EN ISO 5659-2/ FTIR smoke chamber test.

   Few deviations in pass/fail results are reported but generally the classification of the 70 products according to the ISO 13571 principles is not modified too much by comparison with the CEN/TS 45545-2 classification.

2. With some products the classification is down-graded when a larger scaling factor is introduced into the calculation of ASET. This change in scaling factor in FED/FEC calculations is necessary since it is inappropriate to use a perceived burn area A_s of $0.1m^2$ for all products as is specified in prEN 45545-2.

   A substantial amount of Task Group attention and calculations have been devoted to what criteria should be specified for A_s in calculations of FED and FEC for the required toxicity classification of the different product sectors (ref. Section IV.3). In addition to the small scale tests on 70 products, the full-scale and real-scale tests have provided valuable validation data to help specification of A_s for lining products and passenger seats. The proposed derivations of A_s and its contribution to the scaling factor in calculations of FED and FEC are key steps that should be extended by the new CEN/CENELEC Joint Working Group when it revises EN 45545-2 in 2013.

3. The ASET results make it easier to determine compliance with the requirements of operation categories for trains on European networks.

   The proposed TRANSFEU D6.5 method gives better discrimination than the CENTS 45545-2 method. The shape of the gas concentration versus time curve is very important. The method in CEN/TS 45545-2 measures the CIT value at 4 minutes and 8 minutes. Where a product gives a value of CIT = 1 at less than 4 minutes or between 4 and 8 minutes, this behaviour could be missed and the product assumed to have passed.

4. The EN ISO 5659-2 procedure coupled with continuous FTIR gas analysis should be specified as the combustion method for toxicity classification in the revision of EN 45545-2.

5. The prEN 50399 cable ladder test with continuous FTIR analysis may be used for classification of the toxicity of gases from combustion of cables in EN 45545-2.

6. The new test method of EN ISO 5659-2, with continuous FTIR measurement of gases, produces data that permits the amount of toxic gases produced during the combustion versus time to be evaluated during a 20 minute exposure period. This technique enables required ASET times to be determined for various categories of railway vehicle as specified in EN 45545-2 and the European TSIs.

7. The use of ISO 13571 for classifying the toxicity of combustion gases from railway products based on time to compromised tenability has been validated by a combination of small-scale, full-scale and real-scale fire tests. This standard also allows regulators to select threshold criteria that take into account the susceptibilities of passengers (including young children and elderly people). Calculations of FED and

FEC have been performed for 23 railway vehicle product sectors prescribed in EN 45545-2. The FED/time and FEC/time graphs for these products are presented in TRANSFEU D6.5 Part 2 (ref. 24) with the FED and FEC threshold criteria of 0.1, 0.2 and 0.3 shown on each graph. This information should assist regulators when defining technical specifications for European railway vehicles.

8. The CEN/CENELEC JWG decision to adopt single point gas analysis for classification of toxicity of fire effluents in EN 45545-2 (Edition 1) is a conventional prescriptive one. It does not fit with a Fire Safety Engineering philosophy, which requires a time-based approach to fire development so that compromised tenability times (ASET) may be estimated.

9. Since IMO already specify the use of the ISO 5659-2 smoke chamber with gas analysis for classification of products on various categories of ships, it is recommended that the TRANSFEU methodology for FTIR continuous gas analysis and the derivations of times to FED and FEC tenability criteria be disseminated to IMO as soon as possible.

Section XIII - References

1. TRANSFEU WP3_D3.1P, *Proposals for conventional classification models.*

2. TRANSFEU WP3_D3.2P, *Ranking of products according to Available Safe Escape Time (ASET).*

3. TRANSFEU WP3_D3.3P, *Proposed draft classification system for products on railway vehicles for inclusion in EN 45545-2.*

4. TRANSFEU WP3_D3.4 Part 1 P, *Classification of the toxicity of fire gases from products on European trains.*

5. TRANSFEU WP3_D3.4 Part 2 P, *Product database of classification system.*

6. TRANSFEU WP4_D4.1 P, *Explanation of Available Safe Evacuation Times (ASET) in railway vehicles.*

7. TRANSFEU WP5_D5.4, *Numerical tool for simulation of the passengers' evacuation from train scenarios.*

8. ISO 13571: 2007 (1st Edition), *Life-threatening components of fire – Guidelines for the estimation of time available for escape using fire data*.

9. NIOSH (1997 version), National Institute for Occupational Safety and Health: *Documentation for Immediately Dangerous to Life Concentrations (IDLH).*

10. Purser, D. A. *Assessment of hazards to occupants from smoke, toxic gases, and heat,* SFPE Handbook of Fire Protection Engineering, 2008.

11. TRANSFEU WP3N57, *Draft report on use of FED and FEC methodology to classify the toxicity of fire effluents from products on railway vehicles,* B. Bansemer, F-H.Wittbecker, M.Halfmann and K-H. Richter.

12. TRANSFEU WP2_D2.1.3P, *Standard test method for continuous measurement of fire gases generated in the EN ISO 5659-2 smoke chamber using FTIR spectrometry.*

13. TRANSFEU WP2_D2.2.3, *Report on the statistical analysis of test data from the EN ISO 5659-2 smoke chamber using FTIR spectrometry.*

14. ISO TR 13387 Parts 1 to 8, *FSE aspects of fire effluents.*

15. ISO 13571:2012 (2nd Edition), *Life-threatening components of fire – Guidelines for the estimation of time to compromised tenability in fires.*

16. TRANSFEU WP6_D6.1, *Selection of products, representative fire scenarios and real scale tests.*

17. TRANSFEU WP6_D6.2.1, *Report of full-scale tests on passenger seats.*

18. TRANSFEU WP6_D6.2.2, *Report of full-scale tests on wall panels.*

19. TRANSFEU WP6_D6.2, *Report of burner exposure to wall*.

20. TRANSFEU WP6_D6.3, *Report of real-scale tests for Scenario 1A and 1B.*

21. TRANSFEU WP6_D6.3, *Report of real-scale tests for Scenario 2A and 2B.*

22. TRANSFEU WP6_D6.3, *Report of real-scale tests in train compartment*.

23. TRANSFEU WP6_D6.4, *Prediction of the Available Safe Evacuation Time (ASET) according to the critical effects on people in specific coaches from raw data obtained by small-scale tests in WP2.*

24. TRANSFEU WP6_D6.5 Part 2 P, *Product data-base of classification system for toxicity of combustion gases.*

25. EC FIRESTARR Project, SMT-CT97-2164, 2001, *Reaction to fire testing and classification of products on railway vehicles.*

26. ISO TS/5658 Part 1:2006, *Reaction to fire tests – Spread of flame – Guidance on flame spread*

27. ISO 5658 Part 2:2006 and Amendment 1:2010, *Reaction to fire tests – Spread of flame – Lateral spread on building and transport products in vertical configuration*

28. ISO 5658 Part 4:2001, *Reaction to fire tests – Spread of flame – Intermediate scale test of vertical spread of flame with vertically orientated specimen.*

29. EN ISO 9239 Part 1:2002, *Reaction to fire tests for floorings – Flame spread using a radiant heat ignition source.*

30. EC ROLAND Project 1994, *Intermediate scale testing of vertical flame spread on vertically orientated specimen.*

Annex A

The burnt areas of the double-deck coach test (scenario 2A): Wall, ceiling and seat

Photograph A.1

Photograph A.2

Photograph A.3

Annex B

The burnt areas of the double-deck coach (scenario 2B): Wall, ceiling and seat

Photograph B.1

Photograph B.2

Photograph B.3

Annex C

FDS simulations of EN 45545-1 Ignition Model 5 (Type 2 burner)

Full-scale test bench modeling has been conducted in WP5 and the calculated burn areas determined on wall panels [19, 23]. The study of the flame height, of the stability of flames and of the impacted surface areas was done using numerical simulation. The CFD software used to obtain these simulations was FDS v5, developed by NIST.

Figure C.1 and C.2 show flames at the two periods 75kW and 150kW used in the fire programme for the EN 45545-1 ignition model 5. Figure C.3 is a photograph of this burner at the 150kW stage. The dimensions of the corner rig for full scale tests are walls 1.5m x 1.5m, ceiling 1.5m x 1.5m and height 1.5m. The burner flame base is 300mm x 300mm.

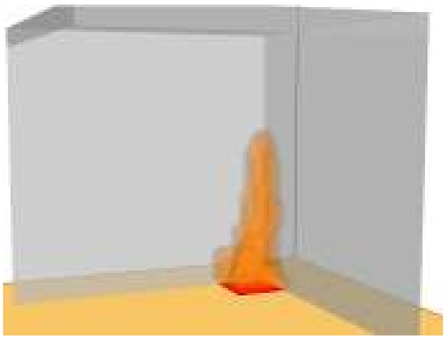

75 kW

Figure C.1

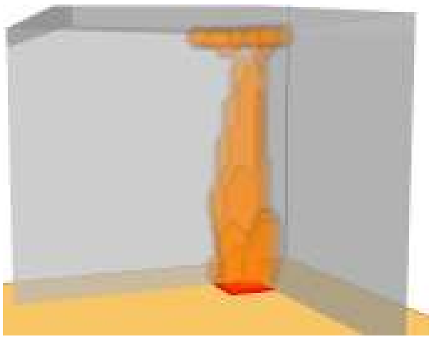

150kW

Figure C.2

Figure C.3

First period (2 minutes @ 75 kW)			Second period (8 minutes @ 150 kW)		
Incident Heat Flux (kW/m²)	Impact on walls (m²)	Mean incident heat flux in that area (kW/m²)	Incident Heat Flux (kW/m²)	Impact on walls (m²)	Mean incident heat flux in that area (kW/m²)
≥ 20	0,428	46	≥ 40	0,698	68

Table C.1: Measured surface burn areas and mean incident heat flux in full-scale wall/corner tests at the two periods of the fire programme with EN 45545-1 Type 2 burner

Product reference	Surface area burnt (m^2)
IN1-5	0.62
IN1-7	1.03
IN1-8-1	0.72
IN1-8-2	1.09
IN1-10	0.82

Table C.2: Observed surface areas of wall panels burnt in Task 6 full-scale corner test