PRESENT-DAY DESIGN FIRE SCENARIOS AND COMPARISON WITH TEST RESULTS AND REAL FIRES: STRUCTURES & EQUIPMENT

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ABSTRACT

This paper discusses present-day design fire scenarios and comparison with test results and real fires. Use has been made of various sources, collected in the frame of the FIT, DARTS and UPTUN project. The purpose of the paper is to demonstrate the spate in current design fire scenarios through the member states and hence the need to harmonise the approach towards design fire scenarios in Europe.

1. INTRODUCTION

A fire could be defined as an unwanted and unforeseen fire as regards: place, size and time of occurrence, with extreme heat and excessive hot and/or toxic smoke development and spread. A scenario in this respect is an assumed course of events, following the ignition of the fire. A design fire scenario thus represents a possible outcome of a fire incident, based upon a number of governing conditions, for example the quantity and characteristics of combustible material, the arrangement of materials, tunnel geometry, fire compartment size, availability of ventilation, position of the fire in the tunnel, location of the fire on the vehicle/rolling stock (e.g. underneath the train, overheated breaks, …).

2. DESIGN FIRE SCENARIOS

A design fire scenario might concentrate on the pre-flashover stage only, when occupants are evacuating the train fire compartment, on post-flashover, when the impact on the tunnel structure becomes important, or on both stages. The pre-flashover stage is associated with a growth rate, e.g. slow, medium, fast or ultrafast.
When considering fire scenarios mainly two kinds of fire scenario curves are important, rate of **heat release curves** inside the train (the RHR curves are used for zone modeling and CFD) and **temperature time curves** (T-t) outside the train (the T-t curves are used for fire testing and analysis of impact of fire on the structure.

It is worth noting that as far as T-t scenarios are concerned, the temperature is spatially homogeneous (because of its mostly primary function to serve as input for testing in furnaces) so that stresses / strains due to large temperature gradients are sometimes not correctly accounted for by these scenarios. Therefore, also depending on the test set-up in some cases they give a very general result only but do not give us any detailed information).
The **smoke production rate** can also be needed for ventilation and escape purposes and can theoretically be derived form the rate of heat release. Further, as also mentioned in the introduction of the FIT document, four different design fires can be needed. These fire scenarios are all mainly based on the temperature time and RHR curves, and are presented below;

Design fires referring to the structural load
These design curves are needed to validate the resistance of the structure to a fire. Today these design fires are mainly based on the results of the Eureka tests, ISO-curves, Eurocode 1 curves, Hydrocarbon curves and Rijkswaterstaat curve. These are all temperature time (T-t) curves that refer to the temperature of the gas that the structure is exposed to, thus the convective temperature. However, for the heat transfer towards the structure during fire, radiative heat fluxes are in fact dominant. The radiative temperature is a measure for all the radiative heat coming to a certain point on the surface of the structure. This radiation comes partly from the flames and partly from the surfaces of heated materials. In a real tunnel, if the gas temperatures near a certain point on the surface of the structure are the highest, this does not automatically mean that this point also receives maximum heat radiation because this point may “see” many colder surfaces. For assessment of the structure during fire, it is a safe assumption to assume that the structure is not only exposed to the high convective temperatures but at the same time is receiving large radiative fluxes from all directions. In a fire test, using wire thermocouples mostly convective temperatures are measured; using plate thermocouples enables both convective and radiative temperatures to be taken into account. However, with insulation on the heated side of the furnace walls it is to be expected that all furnace wall surfaces will be almost the same temperature as the convective gas temperatures of the T-t curve, and so the structure will be exposed both to maximum convective and radiative temperatures in the test.

Design fires referring to ***ventilation*** *purposes with a view to control smoke spread*
The aim of ventilation is two-fold: i) prevent back-layering, or ‘control’ the smoke in order to provide a smoke free escape route for train occupants and ii) reduce the smoke temperature by dilution and advection of smoke so as to reduce the thermal load on the tunnel structure. Therefore, ventilation measures are based on smoke production rate and smoke temperatures. Thus this is based on both the rate of heat release curves and the temperature curves. It is normally accepted that the fans above the fire will fail due to high temperatures. However, fans located some distance away from the fire can be tested in a furnace according to a lower T-t curve.

Design fires referring to the ***equipment*** *of tunnels*
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Design fires referring to rescue and escape
Temperature, visibility, concentration of toxic gases, radiative heat fluxes, and available escape time should be assessed according to these design fires. Ventilation and fire resistance of equipment must also be taken into account in these calculations. These design fires referring to escape are based on rate of heat release curves and indirectly on temperature-time curves (because the ventilation, equipment, and structural resistance is based on this).

In this document an overview of different available design fires for rail vehicles and their background will be mentioned.

3. ACTUAL FIRES

One aspect which must be taken into consideration, among others, is that fires described in the sources available (e.g. investigation reports, fire service operational reports, publications in specialist journals, newspaper articles) are not always described in sufficient detail for the problems which occurred relating to fire protection and those encountered when fighting the fire to be adequately assessed. Furthermore, the technical developments during the assessment period also have to be taken into account. It is certainly possible that a fire which occurred in 1970 might not occur at all today, or certainly not take on the same proportions, as a result, for example, of the numerous improvements that have been made to vehicles in the intervening period. Against this background a total of 85 fires have been analysed in underground traffic systems. These selected fires are divided up as follows:

- 45 fires in underground railway and suburban railway tunnels
- 11 fires in main-line railway tunnels
- 29 fires in road tunnels.

These fires are in no case representative for the risk in other traffic modes.
Below, a summary is given as example of available information concerning heat output and fire development from real fires of passenger trains and freight trains. These values could be further used to develop and validate design fires in the scope of the UPTUN project.

FIT-Document 5th Draft
This document mentions relevant information the channel tunnel fire where a freight train caught fire.
The fire happened in the Channel Tunnel on Nov. 18th 1996. The average rate of heat release over a three-hour period was estimated to be 150 MW. The peak rate of heat release of 370 MW occurred 60 min into the fire. The ventilation was directed towards the area where the least cargo was placed.

Department for Transport; Inquiry into the fire on heavy goods vehicle shuttle 7539 on 18 November 1996.
This document describes the fire in the Channel tunnel. At approximately 22.00 a train travelling from France to the UK stopped 19km from the French portal because a fire was seen in the second train rake carrying HGV's. The fire was extinguished 7h later, 05.00h, on Nov. 19. The evacuation of passengers started 23minutes after train was stopped, and concluded 7 minutes later. A number of passengers were brought to the hospital with problems related to smoke inhalation. The fire caused considerable damage to 480m of the tunnel. The area most severely damaged by the fire was 50m in length. The train consisted of two rakes. A HGV shuttle train rake generally comprises 14 to 15 carrier wagons with a loader wagon at each end. The carrier wagons are of semi-open construction and are designed to carry heavy goods vehicles up to a maximum weight of 44 tons. The front locomotive on the incident train and the front rake were not damaged. In the second rake the front loader wagon and the first carrier wagon appeared salvageable. The following three carrier wagons were seriously damaged. The following ten carrier wagons were irreparable. The rear locomotive suffered severe damage. Based on the type of fuel it is assumed that a maximum value of 350MW was achieved at some stage during the fire. Overall temperatures in the tunnel during the fire appear to have been about 800ºC, but there were localised areas around a HGV loaded with frozen fat that the gas temperatures were up to 1300ºC. Elsewhere, softening of pipes and cables suggests that gas temperatures of 1100ºC were reached.

Fireservice.co.uk: Summit tunnel fire
The fire took place 20th December 1984. The incident involved the derailment of a petroleum tanker train consisting of 13 tankers each containing 100 tonnes of petroleum spirit. The driver of the train and the guard noticed the fire immediately after the derailment occurred and by the time the fire services arrived one tanker was on fire. The driver of the train re-entered the tunnel with the fire services and drove out the locomotive with the three tankers that were still on the rails. 30meters away from the tankers, the fire fighting crews who entered the tunnel met intense heat and withdrew.

Fire, April 1985, "West Yorkshire and greater Manchester combine expertise, Summit tunnel: the Lessons"
The Summit tunnel is 2663m long. It has 13 ventilation shafts along its length varying form 28 to 94 metres. The initial call, on the day of the incident, was received at the fire brigade at 0608. The locomotive with the remaining tankers was driven out at 0840. The fire was ventilating up two shafts, sending flames of 120 metres (!?) up into the air. Gas temperatures of 1200ºC were later confirmed. The fire was fought during several days. It was estimated after the fire that 25 tons of products remained in tankers 12 and 13.

Fire	Date	Tunnel Length	Type Train	Amount of wagons	Wagons de-stroyed	Cause of fire	Duration of fire	Temperatures	Heat output
Channel Tunnel	18 / 11-1996	50km	Freight	24	10 + 3 seriously damaged	Un-known	7h	1300ºC localised areas, 800ºC overall, 1100ºC other spots	Max. 350 MW
Summit Tunnel	20 / 12 - 1984	2,66km	Freight - petrol	12 (- 3 taken out)	7	Derail-ment	> 24h	>1200ºC	
Howard street tunnel, Balti-more, USA	July 18, 2001	2,65km	Freight	57	10 on fire	Derail-ment	>12h	1000ºC within flames, 800ºC wall within flames, 500ºC average within 3-4 wagon lengths, 400ºC wall temperature within 3-4 wagon lengths.	50MW

As can be seen in the table above, only temperatures and heat out puts are available from three fires, all of these involving freight trains. The fire duration of these cases is often very long and the gas temperatures at localized areas are above 1000ºC. In these cases many factors play a roll, such as direction of ventilation, possibility of taking out wagons of the tunnel or not.

4. FIRE TESTS

One large series of fire tests has been performed concerning trains in tunnels, these are the Eureka FireTun tests. Documentation concerning these tests is available through various sources. In this chapter fire tests that have been conducted on trains in the open air will also be presented. Also literature references made in the studied literature that can be considered useful for the project will be mentioned.

4.1 Proceedings of the International Conference on Fires in Tunnels, Boras, Sweden, October 10-11, 1994.

Haack, A.; Introduction to the Eureka –EU 499 FIRETUN Project.
This article presents the most important findings from the Eureka project. It presents the gas temperatures that were found inside the tunnel during the burning of the trains. It says that the gas temperature of most rail and bus tests reached maximum values of 800 –900ºC and in one case 1000ºC. It also says that along the tunnel the temperature quickly decreased over the length of the tunnel, for a rail car the temperature was divided in 2 within a length of 20m. The railcars had a peak rate of heat release of approximately 15-20MW. All rail cars registered a fast development during the first 10-15 minutes. This article further points out the differences of the type of vehicle roof on the damage to the vehicle and the tunnel. Steel roofs resisted the heat where plastic and aluminium vehicles did not. The damage to the tunnel was thus larger in the case of an aluminium roof than with a steel roof.

This article further refers to a STUVA project [*Heffels, P., Marquadrt, H-J., Staub, L. 1984. Verbesserung des Brandschutzes in Tunnelanlagen fur Strasses-, Stadt-, und U-Bahnen, STUVA research report 1984*] which arrived at the following conclusions: Given the rail bound vehicles used today, fire flashover must be reckoned with 7-10 minutes after ignition. The fire duration can be between 30 minutes and several hours.

Richter, E., and Vaquelin,O .; Description of measuring techniques used in the Eureka project
The following table presents the fire load of a number of rail vehicles used in the Eureka tests that was estimated based on the total fire load in the wagons:

Test vehicle	Fire Load
Rail car with coach body mad of steel ICE-standard	63 000 MJ
Rail car with coach made of steel IC-standard	77 000 MJ
Joined rail car, part Al-part steel	57 500 MJ
Subway car with steel body	33 000 MJ
Subway car with Al body	41 000 MJ

Richter, E: Propagation and development of temperatures from tests with railway and road vehicles –comparison between test data temperature time curves of regulations
This article presents temperature distributions that have been shown in the tests train fires. A figure in this article shows the temperature distribution in the ceiling during the tests with the rail cars. During the tests with the railway cars the maximum gas temperature below ceiling of the tunnel varied between 700ºC (railway car with steel body), 800ºC railway car with steel body ICE standard, and more than 900ºC, joined railway car. This article also gives a diagram of the maximum temperatures in tunnel cross-sections during the fire tests with long distance trains as fire loads. The steel cars gave temperatures between 400 and 600ºC in the roof and on the walls, while the joined steel- aluminium car gave rise to a temperature above 900ºC on the roof and the walls. In the case of long-distance trains maximum temperatures around the wagons were observed by the joined ICE-cars with Al and steel body after 40 minutes, and by the cars with steel body after 70- 100 minutes.

Ingason, H; Heat release rate measurements in tunnel fires
This paper presents the rates of heat release that have been derived using O_2 consumption technique during the Eureka Firetun tests. A figure is shown that presents the rate of heat release for a German passenger train of IC standard with a steel body. After approximately 25 minutes a maximum of 14MW was reached, the RHR then diminished to approximately 6MW after 30 minutes, where it stayed for 50 minutes until it increased again to 12MW after 110 minutes. Thereafter it decreased to 5MW after 130minutes.

Blume, G.; Smoke and heat production in tunnel fires – Smoke and hot gas hazards
This article presents the temperature measured at 2m height outside the IC standard steel body railway car in the Eureka tests. The maximum temperature outside the railway was measured 100 minutes after the fire started because the fully developed fire did not reach the rear of the car before that. The maximum gas / flame temperature amounted approximately 700ºC.

This article further presents the temperatures that were measured inside the carriage at three different points and one can clearly see the fire propagation within the wagon. The maximum gas /flame temperature close to the place of ignition of the fire attained 800ºC after 40 minutes. In the middle of the carriage the maximum gas / flame temperature amounted approximately 900ºC, 70 minutes after ignition. On the other end of the carriage the maximum gas / flame temperature of approximately 950ºC was reached 90 minutes after ignition.

Barber, C., Gardiner, A., and Law, M.; Structural fire design of the Öresund tunnel
This article refers to a number of fire tests that were presented as a part of a study for the fire test exposure for the Öresund link. Among others fire test that were done by Ove Arup for British Rail and Thai Railways are presented. It is stated that in a passenger carriage flashover will occur when the heat output is in the order of 1MW. Significant heat exposure is expected to last about 30 minutes after flashover. It presents results of maximum rate of heat release from four trains: British rail 16MW or 7MW depending on the age of the carriage, Thai Railways 16.3MW or 14.0 MW depending on the type of carriage.
It presents a full RHR curve for a Thai sleeping car including all the possible objects in this car, including sheets, pillows, hardboard, baggage, etc. It shows that flashover will be almost immediate and that the peak rate of heat release of 16MW will be reached after 16 minutes. The total fire will last for approximately 30 minutes.
It is further stated that British Rail have advised 30MW as an indicative fire size for diesel locomotives. For older type multiple units of electric locomotives electric motor fires of the size of 6.8MW have been calculated for Hong Kong's MTR system.

4.2 Safety in Road and rail tunnels- Fourth international conference, Madrid, Spain, 2-6 April 2001

H. Ingason; An overview of vehicle fires in tunnels
This article gives an overview of tests and RHR from the Eureka tests with different vehicles. This article presents the same values that have been presented above in the Eureka tests. It is further stated that a fully developed fire in a railway car will behave as a compartment fire and using the following formula: $RHR=1.5A_w\sqrt{h}$ where Aw is the total broken window area in m2 and h is the height in meters.
It further gives information from the channel tunnel where the max RHR was assumed to be 350MW and 150MW over a three hours period.

4.3 Proceedings of the International Conference on Catastrofic Tunnel Fires, Boras, Sweden, November 2003

In September 2003 large scale fire tests were carried out in the Runehamar Tunnel in Norway. In these tests the fire behaviour of semi-trailer cargos in a tunnel was studied systematically in order to obtain new knowledge about the fire development and fire spread in the cargos and the heat exposure to the tunnel linings in the vicinity of the fire. Information about upstream thermal conditions was also obtained during these tests. The fire tests were initiated and headed by SP Swedish National Testing and Research Institute. Active partners in the performance of the tests were SINTEF/NBL Norway and TNO Centre for Fire Research, the Netherlands. The measurements were performed a.o. within the frame of the UPTUN project and as such co-sponsored by the European Union.

Test nr	Test cargo	Heat content (GJ)	Weight (kg)	Mass ratio cellulose/plastic
1	Wood pallets and plastic (PE) pallets	207	9,900	82/18
2	Wood pallets and mattresses (PUR)	113	6,100	82/18
3	Real furniture + 10 tyres	150	7,700 + 800 (tyres)	82/18
4	Plastic (PS) cups in cardboard cartons	52	2,600	81/19

Main, preliminary, conclusions of the Runehamar tests are:

1. In all tests a rapid fire spread occurs: within 5 to 10 minutes the whole cargo is on fire. A first attempt to estimate the fire spread was partly successful for test 1 and test 3.
2. In test 1, there is a great risk of fire spread to other vehicles at a distance of 5m behind (upstream) the burning cargo during a period of 55 minutes. This risk also exists in the other tests, but for a shorter duration of 7 to 10 minutes. More accurate estimations of the risk of fire spread in case of a heavy good vehicle fire will be made in the near future.
3. A first attempt is made to correlate the heat flux to the wall with the strength of the fire, but more sophisticate modelling is required.
4. In all tests the thermal load on the wall exceeds the standard ISO-834 temperature curve for building materials for a duration of 15 to 30 minutes. Other fire curves seem more appropriate to represent the thermal load on the wall during these periods, as e.g. the hydrocarbon Euro code 1 curve.
5. The fire brigade will be able to attack the fire despite the radiation from the fire.

Fire tests: summary and conclusion

In principal, only a small amount of tests are available from fires in passenger trains in tunnels. For freight trains a number of tests are indirectly available, because the loads of a freight trains resemble in many cases the load of a HGV. Available fire tests on HGVs will be explained in the chapter on road tunnels.

There has only been one large test series concerning passenger trains in tunnels: the Eureka FireTun tests. A large amount of literature is available from theses tests. Two tests on passenger trains outside tunnels have also bee performed. These are tests by Ove Arup for British Rail and Thai Railways. One can see that from these tests the fire development and final RHR and peak temperatures depend on numerous factors, such as the interior of the train, the train body, and the ignition source. This clearly supports the statement that a design fire scenario for a tunnel with a number of different trains passing through will only be general in nature. For the escape of passengers however it would be recommendable to have a design fire per train type going through the tunnel in order to be able to account for correct evacuation.

A summary of results from the Eureka and Arup tests are presented below.

- **Temperatures:** Gas and flame temperatures in the Eureka tests depend on the type of carriage. In general the gas /flame temperatures reach approximately 700 –1000ºC. The temperatures were lower for steel bodied wagons than for trains with Al-bodies. In the tunnel roof and walls the steel cars gave temperatures between 400 and 600ºC, while the joined steel- aluminium car gave rise to a temperature above 900ºC on the roof and the walls.

- **RHR**: The maximum RHR is available for three different tests. For older type of train wagons (13MW), newer type (19MW) and a joined Steel-Aluminium wagon (43MW). Maximum rate of heat release from the British rail trains16MW or 7MW depending on the age of the carriage. Thai Railways 16.3MW or 14.0 MW depending on the type of carriage. British Rail have advised 30MW as an indicative fire size for diesel locomotives. For older type multiple units of electric locomotives electric motor fires of the size of 6.8MW have been calculated for Hong Kong's MTR system.
- **Flashover:** Flashover is said to occur when the heat output is in the order of 1MW or be almost immediate according to one source in the Arup tests. STUVA [ref.] states that fire flashover must be reckoned with 7-10 minutes after ignition. From the Eureka tests one could see that the temperature increased rapidly at the place of ignition. However in the entire compartment it took 25 to 90 minutes for flashover to occur.
- **Fire Duration:** The total fire duration for the Eureka tests varied from 60 minutes (Half a railway car with the body made of steel and materials according to the new design) to approximately 180 minutes in a F11 railway car with a steel body and an IC interior (former design of train material). In the Arup tests [ref.] it is said that significant heat exposure is expected to last 30minutes after flashover (which is almost direct). This was confirmed in their tests of the Thai sleeping wagons.

5. DESIGN FIRES

This chapter presents articles that are related to the different stages of a design fire.

5.1 Safety in Road and rail tunnels- Fourth international conference, Madrid, Spain, 2-6 April 2001

M. Molag, R. van Mierlo and T. Wiersma; Realistic fire scenario's for safety assessment of train fires in tunnels

The design fire in this article has mainly been done looking at the escape of passengers. Therefore the fire growth has been the most important point and the maximum RHR or the decay phase, have not been studied.

This article mentions that a fire can have four phases, - smouldering, fire growth, flash over, and decay. The smouldering phase was seen to be short in carriages, i.e. 2-5 minutes. It has been seen that on the HSL [future high speed train line connecting Amsterdam to Paris] the detected smouldering period varies between 30 and 120s. If the fire is big enough then it can grow with a rapid fire development. Rapid growth means 150s after the start of the fire the RHR is 1MW. Although rapid growth is possible, average growth, slow growth and die out of fire have been observed. It has been derived that 3% of the trains had a fast flashover, 6% had an average flashover and 6% had a slow flash over. In 85% of the carriage fires flash over did not occur due to a small RHR and / or the windows cracked at an early stage of the fire.

5.2 Tunnel Fires and Escape from tunnels, International conference, 5-7 May 1999, Lyon, France

Munro, J. and Scott, P.; Tunnel Design Fire Assessment

An internal carriage design fire has been based on a baggage fire with a total heat output of 1.4MW. The peak RHR of the baggage fire was estimated to be 320kW.

5.3 Long Road and Rail tunnels: First International Conference, Basel Switzerland 29 November – 1 December 1999.

Broder, B. and Gerber, P.; Risk-based design of long railway tunnels up to 20 km length
In this article a time-event diagram has been developed. It mentions how to calculate different time sequences based on statistical methods and practical test results mainly to look at escape. It shows that the probability of a train on fire stopping in a tunnel gets exponentially greater going from 0.1% in a 15km long tunnel to 10% in a 30km long tunnel to come to the conclusion that more safety measures are needed in longer tunnels.

Høj, N.P. and Bennick, K.; Fire and explosion safety in design of railway tunnel under the Great Belt
This article presents fire loads from different trains and it discusses fire development and spread and standard fires in trains. The fire load of the fuel in some locomotives is 100-140GJ, in 2 fuel tanks of an IC3 train 115GJ, and from a modern passenger vehicle approximately 15GJ. An average freight train might present a fire load of 50GJ, in a hydrocarbon tanker 80000l fuel will represent a fire load of 2800GJ. The fire load of an entire passenger train is 600GJ over a length of 300m. A freight train may have a fire load up to 24000GJ over a length of up to 700m. The rate of heat release in open air can be used to determine the fire strength. The following numbers are given: Passenger vehicle: 0.3MW/m^2, Freight vehicle : 0,5 –1 MW/m^2, freight vehicle Hydrocarbon pool, 2MW/m^2. It is not clear in the article how these values have been derived.

5.4 Passenger Safety in Mass transit 5-6 December 2001, Basel, Switzerland

Pagan, J.; Development of a natural smoke ventilation system for the redesign of Blackfriars underground station,
This article presents a design fire for the LUL. A first rapid growth was assumed until 0.5MW was reached followed by a slow growth up to approximately 5MW after 1000s. The reasoning behind this was that a fire would start involving a small amount of combustible material and then spreading to involve the interior of the carriage.

5.5 Brand Scenario's voor de reizigerstreinen in de tunnels van de HSL-Zuid, TNO-rapport 1999 – CVB –R1992

This report presents the main ignition sources for a train fire based on numbers from London Underground and the Dutch Railways (NS). 38 fires were studied from the Dutch railways, 34 of them were extinguished by the NS personnel or self-extinguished. In four cases the fire services had to act. It further describes different kinds of growth velocities that are possible within a train compartment, saying that ultra-fast to slow growths can be expected depending on the norms that are used for the interior of the train and the ignition source or other reasons. Calculations have been made to see when flashover can take place in a train compartment. In a "fast" fire flashover will take place after approximately 120s, if no windows have fallen out, and 400s if all the windows have broken. It is said that it is to be expected that at least the window closest to the fire has broken, leading to a flashover time of 150s. For a medium growth fire the times to flashover are 190s, 800s and 240s.

For a slow fire growth it is expected that a number of windows have collapsed, and the time to flashover is expected to be around 1600s. It is stated that the main reason for fires in multiple wagons is that the temperature will increase in the tunnel and that burning particles will be spread through the air. It further states that the expected fire duration for a train wagon with fast development is 30 to 60 minutes. For a slow development the expected fire duration of one wagon will be approximately 3h. Fire curves are the presented for a number of different configurations, with fast, medium and slow growth rates that lead to flash over. These are presumed to be valid for 15% of the cases. In 85% of the cases no flashover will be expected and a maximum fire size of 3MW is expected. The maximum rate of heat release has further been studied. It stated that in the Eureka tests values between 13 and 43MW were observed. A value of 0.2 –0.9MW/m^2 was observed.

5.6 Tunnel Fires and Escape from tunnels, International conference, 5-7 May 1999, Lyon, France

Favre, P.; Detailed simulation of smoke movement due to a train fire in the context of general safety considerations for the Gotthard base tunnel
Using the model for fire development of a Eureka carriage as a basis, the fire development of an entire IC train and a carriage fire has been estimated. The carriage fire is assumed to last for 130 minutes, reaching a peak RHR of 10MW after 20 minutes, and staying at this level until 120 minutes. For the entire train, the fire durations for the different carriages have been put together, assuming that the second carriage ignites 50 minutes after the ignition in carriage 1. The third and the rest of the carriages will ignite 30 minutes after the one before them ignited. In this way after around 3h, a 3h long fire with a RHR of 40MW is designed.

5.7 Proceedings of the International Conference on Fires in Tunnels, Boras, Sweden, October 10-11, 1994. Barber, C., Gardiner, A., and Law, M.; Structural fire design of the Öresund tunnel

It is stated in this document that British Rail have advised 30MW as an indicative fire size for diesel locomotives. For older type multiple units of electric locomotives electric motor fires of the size of 6.8MW have been calculated for Hong Kong's MTR system.

Discussion
Research on fires has been concentrating on passenger trains and not freight trains. In passenger trains a fire can affect a large number of persons. In freight trains, the lorry drivers and the train driver will be the only persons affected. In freight trains it is also difficult to predict the fire load, due to the large amount of loads possible. It can be seen in chapter 2 that it is not only in freight trains that the fire-load or fire development is difficult to predict, but also passenger trains are available in many different configurations. Therefore a design fire scenario for a tunnel with a number of different trains passing through will only be general in nature. For the escape of passengers however it would be recommendable to have a design fire per train type going through the tunnel, since this will be the governing factor, in order to be able to account for correct evacuation.

Event tree
One can see that there are many points that can influence the fire growth, such as ignition source fire load, oxygen supply, and of course, different suppression methods. A way to integrate all these different points / measures would be to handle the design fire scenario through an event tree approach. An example of this is given below:

Assume a tunnel which only allows passenger trains to pass. Fire can ignite at two places, a locomotive or a wagon. The cause of ignition can be technical or electrical fault in locomotive or arson or electrical fault in the wagon.

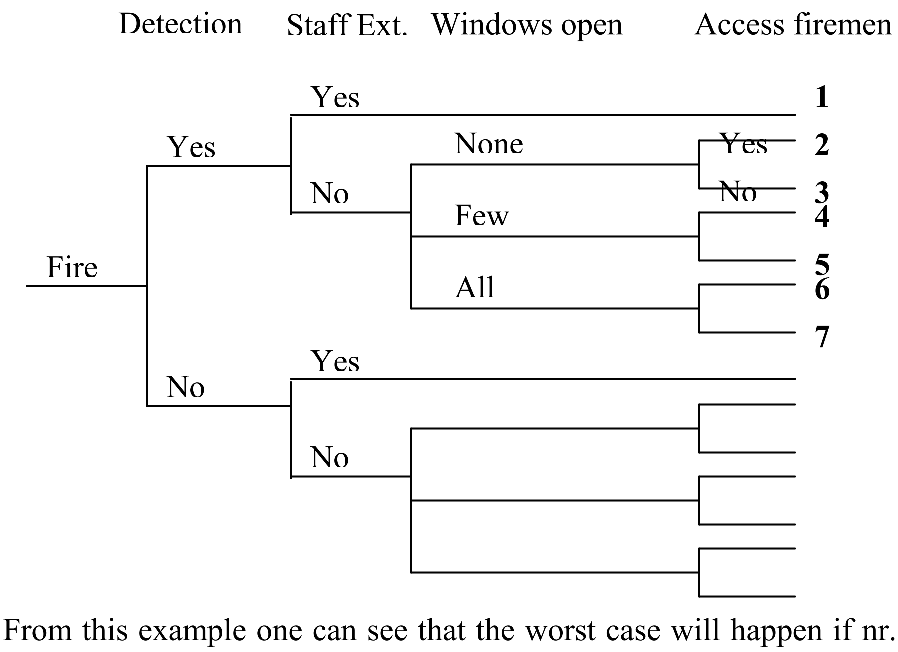
- The first question is concerning detection: Can the fire be detected at an early stage?
- Second question is: Can staff / passengers extinguish the fire?
- Third question is: Will windows be available during the fire growth if only limited number of windows are open flashover will be more rapid. If none are fire can self-extinguish.
- Fourth question is: Will firemen be able to reach the site early and is enough water available?

Depending on the answer a probability of a certain design fire scenario will be given. I.e.: assuming a fire will start, there is a probability of 10% that it will be limited to the size it was when the extinguishing attempt started, etc.

A fire curve (RHR and temperatures) will have to be designed based on a fire in a train. Depending on the different events that take place this fire curve can be lowered or stopped.

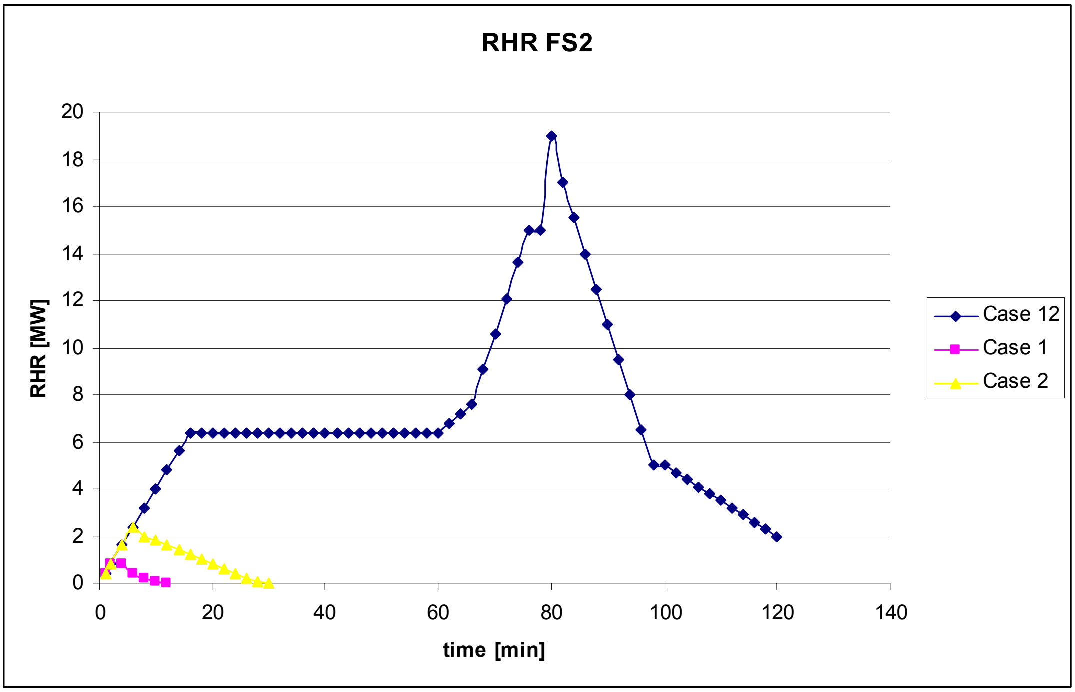
Information concerning probabilities of detection can be quite complete based on various references in this document and could be put into the event tree. The probability of staff extinguishing the fire can also be found. If the windows will be open or not in the beginning of the fire should be assumed to be 50-50. The last question concerning the firemen will have to be judged on a case-by-case basis. In the case of cargo trains than windows open in the early stage of the fire could be replaced with flammable goods in cargo wagon.

Example:



From this example one can see that the worst case will happen if nr. 12 / 5 is applicable, i.e. no detection, staff cannot extinguish, few windows are open, and no access for firemen is available. In this case, depending on the fire load, one can assume a large fire for the passenger train. The best case, where the fire might be limited to one piece of luggage will be nr. 1 where detection is possible and extinguishing by staff is possible. This event tree could be completed with items like fire location, i.e. wagon, locomotive, and ignition source, i.e. arson, derailment, technical failure. These items can have an importance on the probability of detection and staff extinguishing the fire. Also items like ventilation could be taken into account, and statistics of different lengths and types of trains can be put into the tree.

Using the Eureka RHR curve for one FS2 railway wagon and connecting it to the event tree could result in the following:



Multiple wagons could be taken into account by assuming that when the RHR reached 15MW that the wagon beside the ignition wagon is ignited, and that the curve can start from the beginning on the second wagon, thus adding up to the total curve.

This method should be refined and the different cases should be represented in a clear way and be motivated. It is possible that case 12 /5 above in the diagram not is case 12 /5 but case 7 / 14. This should also be looked at.

6. CONCLUSIONS AND RECOMMENDATIONS

"Design fires" are a cornerstone for all aspects of tunnel safety design and accident management. The "design fire characteristics" determine indeed heavily the design of the structure, the ventilation and other safety infrastructure. However, a large scatter is observed regarding the aspect of "Design Fires". PIARC states clearly, and in this paper the authors underscore, that there should be more focus on the definition of relevant fire scenarios and subsequently on the specification of design fires to cover different scenarios. Essential in this respect is to distinguish between fire scenarios for (self)rescue of persons, and the integrity of the tunnel as a system, encompassing both the lining and the equipment.

Within PIARC as well as within FIT, a major attempt has been made to harmonise the approach towards design fire scenarios. The Darts project has been developing a risk-based model that would encompass these scenarios. Within the scope of UPTUN, the design fire scenarios are further detailed, also with a view to other than road tunnels. Recent work performed e.g. in Australia (CSIRO and Queensland Australian fire brigade QFRS) on rolling stock for passenger trains will be incorporated. It is highly recommended to join forces around the world to gather proper information.

This paper discusses present-day design fire scenarios and comparison with test results and real fires. Use has been made of various sources, collected in the frame of the FIT, DARTS and UPTUN project. The purpose of the paper is to demonstrate the spate in current design fire scenarios through the member states and hence the need to harmonise the approach towards design fire scenarios in Europe.

7. REFERENCES

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8. ACKNOWLEDGEMENTS

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