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HIGH SPEED LINE SOUTH: SAFETY CONCEPT– GREEN HEART TUNNEL

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High Speed Line South: Safety Concept– Green Heart Tunnel

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Introduction

The High Speed Line South (Amsterdam-Paris) is the Dutch part of the main European network of high-speed rail links. High Speed rail links offers an efficient and environmentally friendly alternative to transport by air or road. More intensive use of rail at the expense of road and air transport will mean less air pollution, reduced energy consumption and fewer potential traffic fatalities and injuries.

To realise this mission the keywords of the High Speed Line transport system are: **Fast, comfortable and safe.**

Other important objectives are: it has to be properly assimilated into the urban and rural landscape environment and the environmental impact has to be minimised. In this aspect one of the thorniest problems during the decision making process was the question: Should the High-Speed Line cross through the Green Heart of Holland, or shouldn't it. Finally the Parliament approved a route that would run partly through the Green Heart. The most important feature of this route is a eight kilometres long shield driven tunnel, which will conserve a large part of a unique Dutch landscape. This tunnel means very little excavation work will be necessary in this area, therefore, both damage to the landscape and disruption to local residents due to construction work will be minimised.

The official green light, to begin the construction, has been given and construction is now in progress. The entire line is scheduled to enter service by the end of 2005.
The contractor of the tunnel Bouygues/Koop is a French/Dutch Combination. They won the design-construct tender by an alternative design. A huge shield driven tunnel with an internal diameter of 13.30m, which is divided by a wall in two tubes. The original reference design was of two parallel tunnels of 9m internal diameter, connected every 300m by cross passages.
To construct this mono-tube alternative a TBM is needed with a diameter of 14.85m, which will be the biggest soft soil TBM of the world. The entrances of the tunnel are constructed as cut and cover works. In between there are three shafts, where TBM inspection and repair are possible. These shafts are also used for maintenance, air-pressure reduction and emergency escape. Such shafts will also be realised at the cut and cover parts at both sides.

This paper will deal with the safety margins and safety measures of the Green Heart Tunnel to satisfy the high safety concept of this transport system.

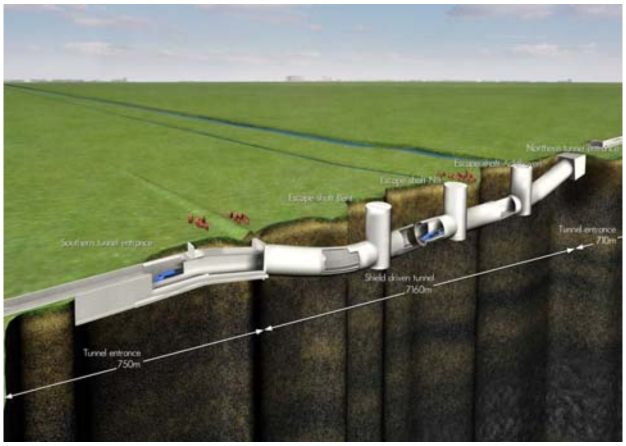

Fig. 1. Artist impression of the Green Heart Tunnel

Safety above all

Safety is an important aspect of the High Speed Line. The HSL Project Organisation won't spare any effort to ensure safety levels that keep the risk of accidents to an absolute minimum. The safety aspects are scrutinised even at the design stage and an integrated safety plan has been developed by the project organisation in co-operation with outside experts including fire, ambulance and police services.

Experiences in France and Germany show that modern high-speed rail transport is inherently safe. The following features guarantee this high safety level:

- **a separate** track with a minimum amount of curves and switches and also free of mixed traffic like stopping trains and slow cargo trains
- **no level crossings**
- **derailment containment provisions** over the total length of the line
- **fences and/or moats** for total isolation of the track from both human and animal interference
- **ultramodern electronic safety system** intervenes automatically when speed limit is exceeded or distance to preceding train falls below safe limit.

Safety in tunnels

Fulfilling the high safety standards over the whole project an inventory concluded that the safety of tunnels is a crucial item, especially in relation to fire. The HSL-south project will pass through five tunnels of which the shield driven Green Heart Tunnel, total length of 8 km, is the longest one.

A passenger train on fire, stopping in a tunnel will cause dangerous situations. Smoke and heat will threaten the passengers and staff. Production of smoke and heat in the tunnel causes a bad atmosphere and people leaving the train to evacuate won't immediately be safe. Without adequate safety measures catastrophes could happen and victims are still a possibility. Referring to recent tunnel accidents like Kaprun, Tauern tunnel and Mont Blanc tunnel, tunnel safety is, therefore, an important issue. Although the cases are strongly different from a high-speed transport system they show that a fire has a great impact. A typical example of 'Small Chance, Big Impact'.

Apart from the general safety measures in the transport system, the HSL-south organisation developed a strategy to reduce and control fire risks in tunnels as much as possible.

This strategy simply is as follows:
- do the utmost to **prevent a fire**. After all, prevention is better than cure
- if, nevertheless, fire does break out, it should be **detected as soon as possible** and the appropriate people brought into action
- **reduce and control the growing fire** to have enough time for evacuation of the passengers
- make **an escape route in the train** safe from the fire
- stop the train for a safe evacuation and emergency assistance, but **don't stop the train in the tunnel, unless** it takes too long to exit the tunnel
- if, nevertheless, a stop in the tunnel is unavoidable, **organise a safe evacuation for passengers** to a safe place via an escape route safe from smoke and heat
- provide **safe possibilities for emergency response organisations** like fire brigade, ambulances, police and care for wounded or escaped passengers
- provide **follow-up care** to reduce and control long term effects

Summarising the five main items:
- **Fire prevention**
- **Fire detection and fire control**
- **Emergency stop in safe place**
- **Self evacuation facilities**
- **Emergency assistance and Follow-up care**

These five main items need to be closely examined within the whole system varying from tunnel design, including tunnel equipment, train and transport operation, to emergency response organisation and plans, emergency equipment and follow-up care. The opinion of the HSL organisation is to put emphasis on the first items of this list in order to avoid catastrophes.

Nevertheless, there will always be a residual risk, no matter how small the probability. It can't be zero. Because of this small chance, passengers need a safe escape route in case of a burning train stopping in the tunnel. Therefore, escape routes to safe havens and safe ingress / egress for emergency response teams are required.

Fire Prevention

Possible causes of fire are:
- arson
- electrical short-circuit or over-heating
- mechanical overheating
- external by lightning or fire in the direct surrounding

Inspection and control by well-trained train crew appears to be very effective in the reduction of arson. Mechanical overheating of wheel bearings and blocked brakes can be avoided by on board or track side detection measures. Another very important aspect is the choice of materials on the train. The use of non-combustible materials will reduce the chances of a fire propagating enormously. A selective choice of material will reduce the growth of heat and emission of toxic smoke.

Fire detection and fire control

A well-trained crew is the most effective way to detect fire in an early stage and to extinguish it. If passengers are able to communicate easily with the crew they can, to this end, inform them with an emergency call or warning signal. According to the TSI Rolling Stock the warning could be given by pulling the emergency brake. However, in a tunnel the use of the emergency brake isn’t a preferred option. Therefore, other communication methods like direct telephone connection could be an option.

Fire detection in special parts of the train where visual inspection is difficult, is another requirement of the TSI Rolling Stock.

A 15-minute isolation of the fire in the compartment where it started is also a TSI requirement to prevent smoke and heat from spreading. This type of fire control is important in order to guarantee a safe escape route for passengers into adjourning compartments of the train.
To ensure that passengers leave the train and evacuate through the escape route to a safe place without being overcome by smoke and heat, is important to endure an effective fire control.

Emergency stop in a safe place

To start evacuation and to provide emergency assistance, ideally, the train should stop in a safe place where passengers during an incident may leave the train in a safe way. This would also provide the emergency services with a good opportunity to reach and enter the train. A tunnel is not the most suitable place for such an evacuation. Long bridges and flyovers create similar problems. In the case of a tunnel incident there is, also, the threat of heat and smoke.

However, in the case of an on board fire where the fire is spreading it could be advisable to stop and evacuate immediately. Therefore, immediately after a fire is detected and suppression measures are taken, a decision has to be made whether or not to stop the train.

Where a train on fire is approaching a tunnel it should be stopped before the tunnel whenever possible. If the train cannot be stopped then the analysis has to be made if there’s enough time to pass through the tunnel and stop at the other side. Essential in the last case is the time that is left for a safe evacuation. Particularly in the situation of low speed transit in combination with a long tunnel the transit time could take much longer and, therefore, greatly reduce the evacuation time under serious conditions.

Overall, the decision “to stop immediately or to pass through” is a complex issue. For the time being in the HSL-situation during an emergency scenario the following goals have been set in the order of priority as stated below:

- stop within five minutes
- don’t stop in a tunnel
- stop as soon as possible
- stop at a suitable place for evacuation and emergency assistance
- make a controlled brake (preferred above an emergency brake)

Priority is given to "**stop within five minutes"** to ensure that enough time is left for evacuation. Assuming that once fire is detected it can be controlled for at least 15 minutes, there are at least 10 minutes left for safe evacuation. There are indications that splitting up 15 minutes of fire control in at most 5 minutes to stop and at least 10 minutes for evacuation is in good balance.

"Don't stop in a tunnel, unless…" is the second priority. An evacuation outside the tunnel is always safer than inside the tunnel, due to the danger of smoke and heat. The exception ("unless") occurs when the scope "stop within 5 minutes" should be exceeded. This depends on the length of the tunnel, the position of the train and its speed. In the most unfavourable position, when the train has passed the point of no return to stop before the tunnel, the train needs a speed of more than 120 km/hr to stop just outside at the other end of the 8 km tunnel in time. This means that by speeds below this 120 km/hr it is preferred for the train to stop in the tunnel and an evacuation undertaken.

The operational decision model is as follows:
- If the train can stop before the tunnel: start brakes–procedure at once.
- If the train can't stop before the tunnel or is already in the tunnel: drive on with safe speed. As soon as the train is outside the tunnel or when 3.5 minutes have passed (even if the train is still in the tunnel) start the brake-procedure (takes 1.5 minutes).

For good operation of this decision model, train drivers need good training and education, as well as on-line information to make the right decision.

Also, very important during this process is, that the train keeps on running. In case of approaching a tunnel it is essential that the train driver can over-rule the emergency brake, that may be activated by a passenger.

Other issues in that respect are:
- Essential running conditions
- Catenaries
- Traffic operation

The emergency brake

Passengers in panic can pull the emergency brake. As stated above this could lead to an unintentional stop in the tunnel, which can only be avoided if the train driver can over-rule the emergency brake and regain control over the train speed quickly enough.

Essential running conditions

The Rolling Stock TSI states that a train with an on board fire has to be able to keep on running for at least 15 minutes at a speed of at least 80 km/hr. This demands essentially running conditions like power-supply, operational control and avoiding unintended braking.

Catenary

A fire breaking out on board a train gives a heat load at the catenary, which can lead to rupture. It is essential that the catenary can withstand specific combinations of fire load and train speed.

Traffic operation

If another train is running in the tunnel in front of the incident train, this could prevent the incident train from exiting the tunnel. Because of the length of the tunnel and optional operation schemes this could occur. In order to avoid this situation occurring an extra condition might be added, that states that only one train can run in any tunnel (that is: per track) at the same time. Operational conditions have to be considered in relation to this safety aspect.

From prevention and operation measures to conditions in the tunnel

The HSL organisation is convinced that measures at the begin of the safety chain (pro-action and prevention) are much more effective than measures at the end of the chain (correction and preparation). That is why in this paper, priority is given to these general operational safety measures, before mentioning the particular safety measures in the Green Hart Tunnel itself. The inclusion of these prevention and operational safety measures reduce the probability that a train on fire will stop in the Green Heart Tunnel 10^{-4} to 10^{-5} per year. There is very little probability but, nevertheless, a very high impact and maybe a lot of victims if there are no safe escape routes for the passengers to reach a safe haven.

Also important in respect to this escape route is that passengers have to evacuate on their own, without necessarily, the help of rescue-workers. Simply because rescue-workers could arrive too late for a safe rescue. Waiting for rescue-workers would increase the risk of casualties. This so-called: **self- evacuation** is essential in minimising the amount of casualties.

Self evacuation facilities

The self-evacuation starts already in the train. The requirements of the TSI Rolling Stock state that a fire has to be isolated during 15 minutes after detection inside the compartment where the fire started, to give passengers time to evacuate to another compartment where they are safe from heat and smoke.

Once a train on fire has stopped passengers need a fast and safe escape route to a safe location. To check the effectiveness of such self evacuation facilities a conditioning case has to be defined.

For HSL this conditioning case is a train of about 400m with 2000 passengers and with a fire in one of the compartments at the end of the train. For comparison a double set of a modern international HST has a length of 400m with maximum 750 passengers inside. So the train as considered in the conditioning case is on the safe side and provides growth in the number of passengers in future trains.

Further important issues are:
- a safe and fast dis-embarkation
- a safe escape route
- a safe location
- control of atmosphere
- training and instruction

Most of these issues are integrated in the design. For the Green Heart Tunnel these issues are realised as follows.

Safe and fast get off

The TSI Infrastructure and Rolling Stock require an optimised dis-embarkation at stations. Future standards of platform heights in Europe will be 0.55m and 0.76m above the railhead. In the Green Heart Tunnel along the whole track there are at both sides narrow platforms with an height of about 0.35m till 0.55m above railhead. This provides an acceptable dis-embarkation even in emergency circumstances.

Fig. 2. Situation of train and platforms in Green Heart Tunnel

A Safe escape route

The main escape route is at the inside directly along the partition wall between both tracks. The width of this escape route is about 1.45m. The outside is not intended as an escape route, it is only 0.80m wide and may be seen as additional if the situation requires. The Main escape route is lit up during an emergency, equipped with pictograms showing the shortest way to an escape door to the safe location. The escape route is safe because of the fire control – isolating the fire within the train - during at least 10 minutes after a stop.


Fig 3. Lightened escape route with pictograms

Emergency doors in the partition wall will lead to the safe tube. The distance between these doors is at most 150m. In practice, in the design of the Green Heart Tunnel it is 144m. Therefore, the longest distance to walk to the safe location is 72m. Other requirements for this escape route is a minimal height of 2.20m, a handrail along the wall, a rough surface, no obstacles and no staircases in this escape route to the save location and never slopes of more than 2.5%. The escape doors to the other tube are sliding doors and are 2.40m wide. This is about 0.95m more then the width of the escape route itself, to realise an easy passage, even if people are coming from both sides.

Fig.4. Sliding escape doors

Considering conservative dis-embarkation times (3 sec/p.p.) and low walking speeds (0.5m/s) calculations showed that 2000 passengers can evacuate in about 7 minutes out of a train of 400m under conditions of the Green Heart Tunnel.

Beside the fact that no heat and smoke will come out of the train within 10 minutes after the train has stopped, the escape route is guaranteed during 30 minutes against spalling of concrete during a burst out of fire.

A safe Location

The non-incident tunnel will be a safe location, because it is separated from the incident tunnel by a partition wall. The partition wall, as well as the lining of the tunnel, is provided with fire-protection layer with two hours resistance for the EC-fire curve. This is expected to last at least four hours for the fire loads of this type of high-speed passenger trains. The safe location can be reached by emergency (sliding) doors, which are in the partition wall every 144m. They are fire-resistant for duration of 2 hours. For fire-loads of this kind of train it is expected that they will resist for more than 4 hours. Therefore, this safe haven will remain for at least 4 hours free of heat load. The doors will close automatically after passage, so there will also be no load of smoke. It is noted that there is no smoke during evacuation, because of fire-control in the train during at least 10 minutes after the stop.

The ventilation in the safe tunnel will be started up at the same time as in the incident tunnel and in special cases immediately after passing of the last train through this non-incident tunnel. The ventilation direction will be in the same direction as in the incident tunnel, to avoid a short-cut of smoke at the end of the tunnel from one tunnel to the other. Therefore, the ventilation direction in the incident tunnel is in the running direction and in the non-incident tunnel against the running direction.

The non-incident tunnel is only a safe location if it is free of all rail traffic. Immediately after detecting a fire in a train and after the decision has been made to stop the train in the tunnel the traffic control centre will stop all trains in both directions running towards the tunnel. Also, for the train coming from the opposite direction a decision model is used to decide if a stop before the tunnel is possible. If the train is already too close to the tunnel, a stop is not possible and the train will have to exit the tunnel as soon as possible. In this last situation it could happen that at the moment that the incident train has stopped, the train from the opposite direction in the other tunnel still has to pass. There is a small chance that this passage could happen at most two minutes after the stop of the incident train. During this situation the other tunnel is not yet a safe location and, therefore, the emergency doors will be kept locked. Immediately after passage of this opposite train the doors will be unlocked. In this maximum of two minutes, passengers are getting off the train and are moving to the emergency doors. Some of them could have reached the doors and therefore, will have to wait. This is not a favourable situation but entering a tunnel where a high-speed train will pass is worse.

However, most of the time it will be possible to stop before the tunnel or, if not, the waiting time for opening the emergency doors will be much shorter than the aforementioned maximum of two minutes. An alternative is to stop trains in the non-incident tunnel instead of waiting until they have exited the tunnel.

If all passengers and crew are in the other tunnel they are in a safe location, but not in a nice environment to feel safe. The train crew will inform the passengers that they are safe, but further evacuation out of the tunnel should be possible. The safe tunnel is also lit up along the escape route and the ventilation is started up to ensure that, also, in worse cases if some smoke might enter by a not-closed door, this smoke will be thinned and transported out of the tunnel. The ventilation is, on the other hand, a source of noise and cold wind, which makes a long stay in this safe tunnel uncomfortable.

In the tunnel of 8km length there are 5 emergency shafts situated where people can leave the tunnel by staircases. Use of elevators is not considered safe in emergency circumstances. The distance between these emergency shafts is at most 2 km. Therefore, the longest distance for people to walk might be 1 km.

In emergency circumstances in this safe tunnel pictograms are lit up to indicate the shortest distance to these emergency shafts. Also, the traffic control centre and the train personal will give instruction on how to behave during a safe evacuation.

Fig. 5. Passage to emergency shafts with foot-boards to cross the track

During evacuation people will walk along the escape route (width 1.45m, height 2.2m) to the location of the emergency shaft. There they have to cross the track by getting off the platform (0.35 till 0.55 m above rail head) of the escape route via foot-boards, and step up the platform at the other side. Slab track facilitates the easy and safe crossing of the track. Some people might also leave the escape platform in an early stage and move along the track to the emergency shaft.

Use of the track as escape route is not intentioned, but because of the slab track it is rather easy and also safe to be undertaken.

When passengers have crossed the platform, they have to open the doors leading to the staircases in the emergency shafts.

Fig. 6. Doors to emergency shafts

The shafts are pressurised during emergencies to avoid smoke entering under all conditions. The depth of the emergency shafts is at the deepest point: about 28m below ground level. This is a long way up by staircases. Therefore, the width of the staircases is 2.40m with a handrail in the middle so that people can pass each other. Also, every 2.5m there is a platform to turn direction and to take a rest and halfway up there are so called recuperation rooms of about 50 m2, where people can take a longer rest.

Fig 7. Staircases in emergency shafts

On reaching the surface passengers will reach fresh air and a large paved platform (3000m2) which is connected to the public road. Here emergency response teams will arrive to give assistance to the passengers and to enter the tunnel for inspection.

Fig. 8. Getting outside on surface level

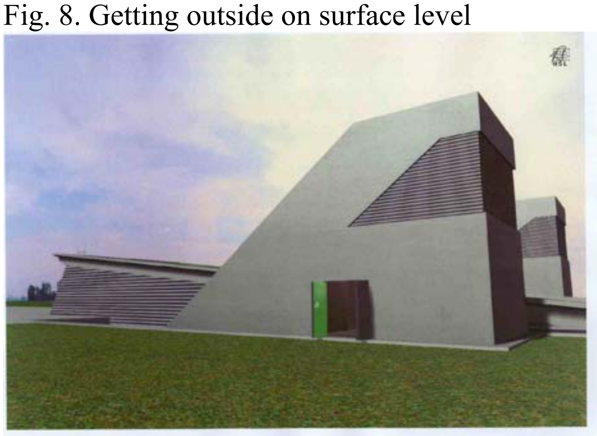

Fig. 9. Building on top emergency shaft at surface level

Control of atmosphere

The escape route is only a safe route if the atmosphere along this route has a controlled airflow. The most critical location is the escape route along the incident train, especially in case of fire.

As stated before the fire control in the train is of the utmost importance. The requirement of 15 minutes fire control within a compartment after detection ensures that at least 10 minutes after the train has been stopped, this escape path will not be threatened by smoke or heat. After these ten minutes the fire may burst out of the compartment and smoke and heat will enter the tunnel. The ventilation will then run at full speed. The smoke will be thinned in the beginning and the atmosphere will be still acceptable for some time. But if the fire grows, it will not be possible to keep the atmosphere safe downstream of the fire. Upstream of the fire the atmosphere will stay fresh because of the controlled flow of fresh air. Passengers upstream of the seat of fire can still escape safely. It is dependant on the location of fire for how many passengers this will be possible.

The evacuation of 2000 passengers of a 400m long train to the safe tunnel at the other side of the partition wall will take about 7 minutes. Therefore, in controlled evacuations all people will reach a safe atmosphere, the safe tunnel. As stated before, the safe conditions in this safe tunnel will be guaranteed for a period of at least 4 hours. Measures to realise this are:

- fire protection on partition wall and tunnel lining
- fire resistant emergency doors
- jet ventilation in the safe tube in the same direction as in the calamity tube

Training and instruction

All measures and escape provisions could be useless if the evacuation doesn't commence immediately. The success of an evacuation will depend on a quiet and controlled start-up. This can be realised by giving well-defined instructions to the passengers in several languages by train-crew.

A good public address system in the train is, therefore, essential. A carefully prepared instruction - recorded on tape – could be a good option. Already during the train braking, passengers can be prepared of what is going on and can get evacuation instructions. Even during evacuation instructions from crew and possibly traffic-control centre are important to ensure that people will continue on a safe escape route.

Special care needs are required for disabled passengers, elderly people, children and possibly injured people. Some of them will not be able to complete the escape route on their own. Others might not be movable at all and will need instructions to stay in a safe place, where they will be transported by emergency response teams. Injured passengers and disabled passengers can be grouped together in the safe tunnel near to the place of the incident train. If the emergency shafts are close by, the less-mobile, elderly people and small children can be grouped together in the emergency shafts, from where later on emergency response teams will evacuate them by the elevators.

For efficient operation train-crew and also traffic-control operators need training and instruction for emergency situations and evacuation. This is one of the requirements to the rolling stock providers.

Emergency assistance and follow-up care

The fire brigade will be warned by the traffic-control centre immediately if a fire is detected or an other incident occurs. There will be regular communication with them about the location of train, type of train, size of incident and the best positions to enter the tunnel. On the basis of this information the fire brigade will drive to one or two of the five emergency shafts in order to enter the tunnel. When they arrive at the emergency shaft a lot of passengers would have already left the tunnel or are still coming out. Apart from giving instructions to these passengers they will enter the tunnel to inspect the situation down in the tunnel. To go downstairs they can use two elevators in the emergency shaft, which transport them fast to track level. The elevators allow them, also, to transport tools for fire fighting and emergency assistance. Down at track level there are even storage-rooms with tools for fire-fighting and emergency assistance. In the tunnel at 75 m intervals there are connections for fire hoses.

Fig. 10. Connection fire-hoses and S.O.S. facilities

Firstly, they will approach the incident train through the non-incident tunnel and undertake initial inspections through the escape doors in the separation wall. If necessary they can also approach the train from the upstream side of the ventilation, because that side is free of smoke and heat. But that decision has to be taken by the fire officer in charge. In the non-incident tunnel they may also meet passengers, which need assistance or maybe also require first medical care. The fire brigade will help these people to evacuate or will call for more assistance. Depending on the situation additional assistance teams can also reach by the emergency shafts where, on surface level, there are paved platforms, which are connected by access roads to the public road. If the size of the incident demands heavy fire-fighting tools and the transport of a lot of (injured) passengers, it is favourable to do all this transport from the entrances' of the tunnel. Also, there are paved platforms of 1500m2 each along both sides of the entrance. Here it is possible to install special trucks, with mobile containers which can ride on the track. Also, fire fighting trucks or ambulances can park here close to the track.

Organisation of the fire fighting operation is the decision of the officer in charge and needs careful preparation, training and instructions. Incident plans have to be prepared for several incidents. Good communication between Fire brigade, police, medical care and traffic control centre are essential.

Moreover, a conditioning case is chosen, that considers a train of 400m length with 2000 passengers and the seat of the fire at the end of the train. In principle, all passengers should be able to escape and evacuate from the tunnel on their own. The assistance, therefore, should concentrate on taking of passengers and giving instructions for a safe evacuation. Only a small group will need more assistance because they will be to unable evacuate on their own.

If the evacuation of a lot of passengers is necessary because they couldn't evacuate the tunnel independently, the decision could be taken to evacuate them with one of the waiting trains outside the tunnel by entering through the non-incident tunnel.

The case of a derailment or collision is not yet complete defined in the normative safety case. However, proposals are made that the emergency assistance does have to be prepared on a number of about 50 injured passengers.

Conclusion

The transportation of people by train through tunnels requires special measures in order to guarantee passengers a safe evacuation in emergency circumstances such as a stopped train on fire in the tunnel.

However, important in realising a safe evacuation are the operational measures on rolling stock and the operation of the transport system. Real safety demands measures on the whole system.

These last measures have the added advantage that they substantially lower the probability that an incident will happen. Because these measures start at the beginning of the safety chain, they are more effective. Nevertheless, there will always remain a risk. In case of the Green Heart Tunnel the risk is predicted as low. However, even for this low risk the possibilities for self-evacuation of passengers have to be good. Even so emergency response teams require facilities to enter the tunnel in a safe way to do their rescue work in a safe environment.