UNDERGROUND TRANSFER TUNNELS IN A MODERN INTERNATIONAL AIRPORT: RATIONAL FIRE SAFETY CONCEPT

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1. ABSTRACT/INTRODUCTION

Absolute protection of life and property from fire in the built environment is unattainable and, even if attainable, prohibitively expensive. However, too little expenditure on fire safety could result in levels of life loss that would be unacceptable to the community. Between those extremes there will exist a set of cost-effective solutions, in which it is feasible to minimize the total cost associated with fire, consistent with achieving levels of life safety, which are acceptable to the community.

The severe consequences of fire in buildings have caused communities to control the design and use of buildings through laws and regulations. The good fire safety record, which has been achieved in Switzerland, may be attributed in part to current fire codes and regulations. However, the regulations and fire codes are both prescriptive and restrictive in their application.

In accordance with the Geneva International Airport authority plans, the construction phase of one new terminal building will be accompanied by the modernization of the existing network of underground passenger transfer tunnels connecting the main building with some satellites located within the runways.

Despite the fact that the Swiss fire codes do not contain special provisions for underground pedestrian tunnels, the local authority having jurisdiction (AHJ) has required, that the existing undivided system of tunnels, total length in reality is no more than 650.0 m, shall be connected to the second, smaller parallel network of egress tubes. This decision is in agreement with provisions of fire codes concerning the structure of means of egress for standard above ground assembly occupancies.

On the other hand, due to the prohibitive cost of this requirement, which considerably exceeds (1.3 times) the fixed budget, the airport authority has decided to carry out a fire hazard analysis and our Institute was authorized, to fulfil this task. The objective of this study was to determine the foreseeable fire safety concept consistent with commonly accepted principles of life safety and property protection.

As a result of the review of NFPA 101®, 101B, 130, 415 [1-4] standards and of some earlier studies carried out for Stansted, Kanzai, Brussels, [5-7] airports, it was decided that the following fire safety measures should be integrated into the structure of existing tunnels:

- The network should be subdivided into smaller sections, separated by smoke resistant walls and automatic door assemblies, (automatic door closers controlled by individual smoke detectors).
- In order to reduce the velocity of smoke spread, each of the above mentioned sections should be subdivided into 2/3 smoke retention compartments which could be achieved through the implementation of smoke curtain boards.
- Implementation of special emergency plans for the airport staff (evacuation of passengers in case of a fire or any other emergency situation).
- The tunnels should be protected by an approved sprinkler system (fast response links).
- In the case of a fire, the heating, ventilating and air conditioning system (HVAC) should function as a non-dedicated smoke control system, (higher exhaust rate) accomplishing one or more of the following tasks:
  - maintain a tenable environment in the tunnel during the fire required for evacuation and intervention of fire brigade,
  - prevent the migration of smoke from the fire area.

Unfortunately, the AHJ has put forward some objections to this proposal, claiming that sprinkler and smoke control systems are prone to failure and therefore could not replace the second, parallel egress tube. For these reasons our institute has carried out the fire modelling analysis based on the application of different computer models, which were used to simulate different phenomena. Fire models CFAST Ver. 3.1.6 [8, 9] developed by the National Institute of Standards and Technology (NIST) was used to predict sprinkler/detection activation upper layer temperature/thickness/composition and sprinkler fire control/suppression.

The NFPA 130 [3] standard and computer model Evacnet 4 [10] were both used to evaluate the egress duration in emergency conditions.

In the modelled fire scenario (slow fire), the activation of sprinkler systems with simultaneous operation of HVAC as smoke exhaust systems provide a tenable environment inside the tunnel during the period of time required for evacuation of the occupants and intervention of fire brigades.

Furthermore, supplementary fire simulations based on the assumption of a simultaneous sprinkler and HVAC systems failure, have shown, that a properly designed HVAC system functioning at ordinary exhaust rate, could be able to maintain the tenable environment during the evacuation of occupants. What is more, even in the case of a faster growing fire (medium fire), properly functioning sprinkler and HVAC systems (operating at smoke exhaust mode) could provide tenable conditions inside the tunnel for a period necessary to achieve complete evacuation of the occupants.

Given the results of fire simulations, someone could rightfully raise questions concerning the feasibility of alternative solutions, based on the installation of an approved smoke detection and properly sized dedicated smoke-control system. Experience has shown, that in favour of a sprinkler concept, the following arguments can be put forward:

- A properly installed sprinkler is able to reduce the temperature of exhausted smoke to such an extent, that standard (not temperature resistant) devices can be included in a structure of non-dedicated smoke control systems. Thus, in this case sprinkler systems can contribute to the reduction of upgrade program cost (use of the existing HVAC system).
- In case of sprinkler protection, the user could make some limited changes to the composition of the fire load (i.e. add some pieces of furniture, install vending machines, etc), which would not cause any variation of content's hazard.
- There is a higher reliability of an ordinary HVAC system over a specifically designed and purposefully built smoke exhaust system.

The supplementary fire risk evaluation, based on the use of the rapid risk assessment method SIA DOC 81 [11], also known as the "Gretener Method", has confirmed the results of the fire modelling analysis. This method, officially recognized by the Swiss authorities having jurisdiction, is widely employed to check the equivalency of particular fire safety concepts with the provisions of national fire codes.

2. OCCUPANT AND TUNNEL CHARACTERISTICS

Hazard of contents

As indicated in the NFPA standards 101® [1], 101B [2], 130 [3], 415 [4] and in earlier studies carried out for Stansted [5], Kansai [6] and Brussels [7] airports, the volumes used by the passengers to access departure or baggage claim areas should be classified within the low fire hazard occupancies. Visits of existing tunnels have confirmed, that due to a very low fire load (< 35.0 MJ/m^2), composed principally of low combustible materials (decorations, advertisement posters, travelators, some isolated steel and plastic seats, electrical installation, etc.), the occupants will be more likely threatened by a slow growing fire as compared to the NFPA 204 [12] and 92B [13] standard time squared fires. The rate of heat release, typical for this type of fire, can reach 1.0 MW, 600.0 sec. after ignition of the first combustible item.

Occupant characteristics and load

As in all Swiss international airports which do not have the special departure zones for domestic flights, all passengers proceeding to these areas will first of all come through the "departures check-in" and passport control. For that reason it is reasonable to assume, that passengers moving inside the tunnel network will carry hand luggage only. According to the airport-authority the disabled persons are always assisted by trained staff and during rush hours the max. specific load of occupants in the tunnel network is not lower than 1.0 person/2.0 m^2.

Emergency response plan

According to the above-mentioned plan, in case of fire four trained members of airport staff should be able to reach each section of the tunnel network within 2.0 minutes after the discovery of the fire. What is more, a closed-circuit television system (CCTV) will allow the personnel in the central supervision station (CSS) to monitor the concerned section. In the case of necessity the staff of CSS shall activate a pre-recorded voice warning system (message in 3 languages – English, German, French) and dispatch to the concerned section further members of staff. The staff of CSS has the possibility even to diffuse live directives through the voice system. In conclusion, it is reasonable to assume that efficiently trained members of airport staff will be able to organize swift evacuation, notwithstanding the multi-lingual nature of passengers carrying hand luggage.

There are several arguments in support of this remark. For example unannounced evacuation drills, performed in 4 Marks and Spencer large retail-stores [14, 15], have shown that trained staff is able to evacuate the clients two times faster than the total evacuation time recommended by some standards [16]. Similar results were gathered up during unannounced evacuation drills organized in Geneva's large retail stores, where the probability to meet clients from abroad is certainly higher than in other cities / countries. In any case, the problem of swift evacuation of multi-lingual people can be resolved only through efficient training of staff in crowd-management.

3. SOME SPECIFIC FEATURES OF THE FORESEEABLE FIRE SAFETY CONCEPT PERTINENT TO THE EXISTING TUNNEL NETWORK

Minimum construction requirements

The network should be subdivided into five smaller sections, separated by smoke resistant glass walls and doors being installed in all accesses leading to each section and satellites. The dimensions of the future sections should be as follows:

1. Length: 170 (1 section), 150 (2 sections), 90 (1 section), 80 (1 section) m
2. Height: 2.8 m
3. Gross width: 8.3 m
4. Usable width (accessible to passengers): 6.3 m

The total width of automatic closing doors, installed in each smoke resistant assembly, should be not smaller than 4.0 m and their height should be limited to 2.2 m. The smoke detectors activating the automatic closing devices should be installed only in the vicinity of the assemblies. In any case, automatic shutting of these doors should also follow the activation of the sprinkler system. After the reaction of sprinkler or smoke detectors, the motors of two travelators, located in the centre of each tunnel, should be switched off as well. The figure no. 1 shows the structure of modified tunnel network.

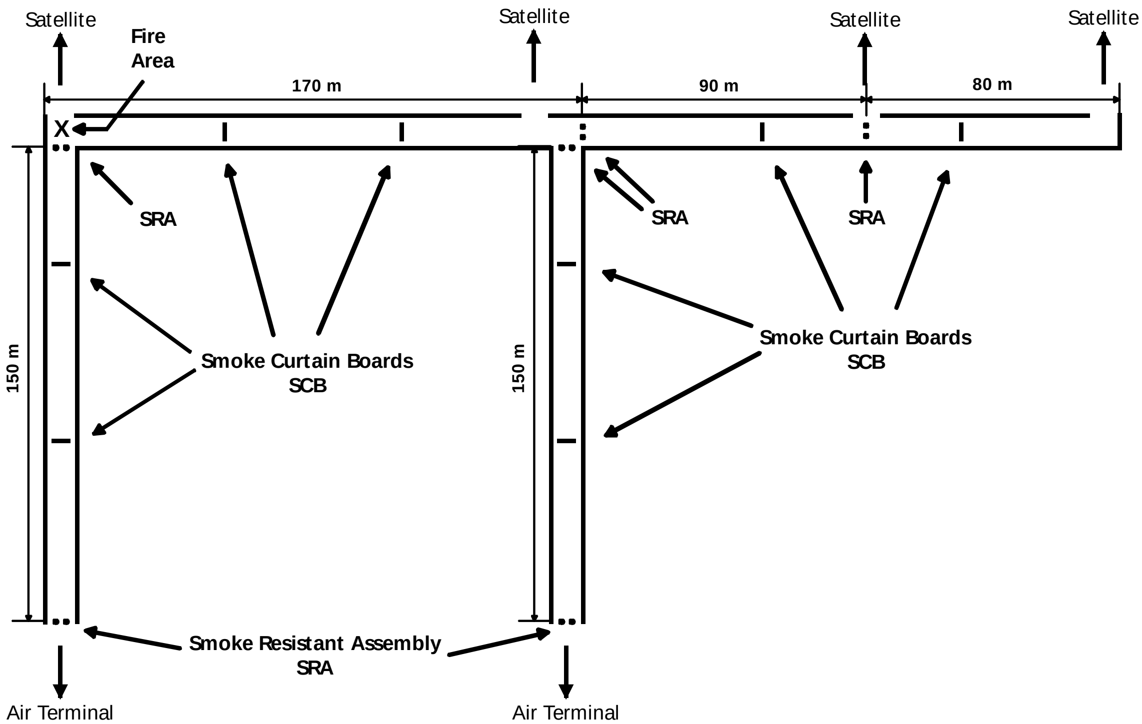

Fig. No. 1: The structure of modified tunnel network

Sprinkler systems

Quick response sprinkler should be installed throughout all the sections of tunnel network.

Heating, ventilating and air conditioning systems (HVAC)

- In the case of fire in one of the tunnels, HVAC should function as a nondedicated smoke-control system, which should accomplish one or more of the following:
  - maintain the tenable environment inside the fire compartment during the time required for evacuation and intervention of a fire brigade,
  - prevent the migration of smoke from the fire area.

- Smoke-control mode

  Activation of sprinkler or smoke detector in the fire area should be followed by the initiation of the operational mode of the smoke-control system, i.e.:

- the air exhaust fans should be able to evacuate the smoke from the fire area at a rate not lower than 4.0 m3 /s. The results of initial fire simulations and NFPA 92B guide [13] were used to calculate the exhaust capacity of the smoke-control system. This exhaust rate should maintain the height of the smoke-free zone in the fire area at 2.3 – 2.4 m above the floor of the fire compartment (for HRR of 0.5 MW),
- in the remaining sections of tunnel network, HVAC systems should continue to function without any interruption, which could prevent the unlimited spread of accidentally spilled smoke outside the fire area.

- Smoke curtain boards

In order to reduce the speed of a smoke front spreading under the ceiling, in sections longer than 100.0 m two curtain boards (regularly spaced) should be fixed under the ceiling. In two shorter sections of the tunnel network only one board should be required, located in the middle of the space. The depth / heights of all boards should not be smaller than 0.5 m.

Emergency lighting

Emergency lighting should be provided in all sections of the tunnel network. Emergency illumination should be provided for not less than 1.0 hour. The lighting facilities should be arranged to provide initial illumination of not less than an average of ten lux.

Emergency egress concept

The concept of emergency egress should be based on horizontal movement of the occupants to the exits provided in smoke resistant assemblies and discharging directly to other sections of tunnel network / satellites / main airport building.

Marking of escape routes and final exits

Over the exit doors, discharging to other sections of tunnel network / satellites / main airport building, should be fixed internally illuminated signs with the worldwide known word EXIT. What is more, the AHJ has required that yellow flashing lights have to be fixed over the exit doors too.
Egress path marking should be composed of internally illuminated directional signs (pointer type) with the word EXIT. The directional signs should be placed on sidewalls, 2.3 m above the floor. On floor level the egress path should be indicated by directional linear strips of photo-luminescent material, placed on the lower part of the sidewalls.

4. BASIS OF THE FIRE MODELLING ANALYSIS

The fire modelling software CFAST / Fast vers. 3.1.6 [8, 9], developed by NIST, has been used to simulate the height of a smoke-free zone, temperature rise of smoke layer, the foreseeable direction of smoke movement within the tunnel network and to predict sprinkler and smoke detector activation. The main objective of fire simulations is, to evaluate the possible consequences of failure of some fire safety system (sprinkler, detection, smoke-control system, closing door devices, etc.) in case of fire. This approach is consistent with recommendations of chapter 5 in NFPA 101® standard [1], concerning the design of performance-based fire safety concepts.

5. HYPOTHESES PERTINENT TO THE FIRE SCENARIO USED IN THIS ANALYSIS

Mode of ignition of the first combustible item of the fuel package

The review of some bibliographical sources [5, 6, 7] and the analysis of initial fire simulation results have shown, that smouldering or very small fires pose no serious threat to the occupants. Accordingly, a worst-case flaming fire scenario, used in the analysis, was based on the assumption, that the flame from a burning wastepaper basket, ignited by a carelessly discarded cigarette, would spread on the surface of other combustible items.

Expected fire growth rate

According to the results of hazard of content evaluation (chapter 2.1) it was assumed that the occupants will be more likely threatened by a slowly growing fire as compared to the NFPA 204 [12] and 92B [13] standard time squared fires.

Most unfavourable location of a burning fuel package

Initial fire simulations have shown, that for the worst-case fire scenario the fuel package should always be situated in the vicinity of one of two exits (see fig. No. 1) in the longest section (170.0 m) of the network. The following remarks could be used to explain this choice:

- fire in the vicinity of smoke resistant assembly with exit doors will reduce the number of primary means of egress in this section,
- due to the dimensions of this section, the number of occupants concerned by evacuation will be higher than in other parts of the network.

Sprinkler and smoke-control system

The fire scenario used in this analysis was based on the assumption, that due to some unknown reasons both systems would be ineffective in case of fire. Accordingly it was assumed, that the exhaust rate of the HVAC system functioning during the fire would be equal to that one used for the ordinary mode of operation (one air change per hour in all sections).

Once more this approach is based on the recommendations of chapter 5 of NFPA 101® standard [1], which gives detailed description of design fire scenarios.

Smoke detection system and automatic closing devices of smoke resistant doors

Furthermore, it was assumed that a smoke detection system would successfully discover the fire, alert the airport staff and activate the closing devices of doors, located in the vicinity of the burning package. The other devices, installed on smoke resisting doors, connecting the fire compartment to one of the shorter sections (length = 90.0 / 150.0 m), will fail to close the doors which will remain open during fire simulations.

Assessment of time necessary for completing the evacuation of concerned sections

- Premovement time
  All assessments were based on the assumption that the occupants will start to move in direction of the available exit 120.0 sec. after reaction of the first smoke detector, which accordingly to initial fire simulations could take place 100.0 sec. after the ignition of the fire. Thus the evacuation of occupants will begin roughly 220.0 sec. after the fire start.
- NFPA 130 [3]
  Calculations, based on principles included in this standard, have shown, that the total time necessary for completing the evacuation, including premovement time, could not be shorter than 390.0 sec (for 536 persons).
- Evacnet 4 [10] Evacnet software is an optimisation model, which was developed to simulate building evacuations. Based on computations, carried out during this study, the total evacuation time, including the premovement period, could not be shorter than 480.0 sec.

Life safety criteria for heat loading and height of smoke free zone

Given the conditions, laid down by AHJ, which stipulate, that the occupants on no account should escape through smoke logged egress routes, only tenability limits for heat were chosen for the purposes of this analysis. As a result of the review of some bibliographical sources [1, 3, 16, 17] the following conditions have been used for this analysis:

- Min. height of smoke-free zone: 1.8 m
- Max. tenable heat flux: 1.5 kW/m^2
- Max. smoke temp. corresponding to heat flux in question: 130.0°C

Intervention of the municipal professional fire brigade

In accordance with the suggestions of the AHJ the total time of fire brigade intervention (arrival and preparation of fire fighting equipment) should not be shorter than 15.0 minutes.

6. ANALYSIS OF FIRE SIMULATION RESULTS

Below are summed up simulation results of occupants egress duration and conditions inside the fire section (see also fig.no.1).

Time after ignition (sec.)	Event
490.0	Time necessary to complete evacuation of occupants – results of calculation, based on NFPA 130 [3] principles
550.0	In one third of section's length, which corresponds with the location of the first smoke curtain and the fire area, the height of the smoke-free zone has reached 1.8 m
580.0	Time necessary to complete evacuation computed by EVACNET 4 [10]
630.0	In the first two thirds of fire section's length, the height of the smoke-free zone has reached 1.8 m
750.0	Smoke starts to spill inside the second shorter section of 90.0 m length
1'000.0	Arrival of fire brigade and beginning of fire fighting operations

Some comments on fire simulation results

At arrival of the fire brigade on place the height of the smoke-free zone (2.3 m) in the second shorter section of 90.0 m length will prevent smoke spread to other sections of the tunnel network. In the fire area (first section) the temperature (105.0°C) of smoke hold 1.5 m above the floor will not prevent the firemen to enter inside the compartment and to fight the fire.

In spite of some fire safety systems failure, the operation of the HVAC system at an ordinary rate of exhaust would prevent the uncontrollable migration of smoke from the fire area and maintain a tenable environment in the routes of egress for the time required for safe evacuation of the occupants.

7. FIRE RISK ASSESSMENT FOR MODIFIED TUNNEL NETWORK BASED ON THE GRETENER METHOD

According to the requirements of Swiss fire codes [18] the Gretener method [11, 19] shall be used to check the equivalency of each fire safety concept which content is inconsistent with regulatory requirements. The evaluations of fire risk carried out with the help of the Gretener method have shown, that the cost-effective fire safety concept, described in this paper, fulfils all requirements relating to the safety of occupants and the property protection.

8. SHORT ASSESSMENT OF ALTERNATIVE UPGRADE POSSIBILITIES

Given the results of fire simulations someone could rightfully raise questions concerning the feasibility of alternative solution, based on the installation of an approved smoke detection and properly sized dedicated smoke-control system. Experience has shown, that in favour of a sprinkler concept the following arguments can be put forward:

- Properly installed sprinkler is able to reduce the temperature of exhausted smoke to such an extent, that standard (not temperature resistant) devices can be included in a structure of non-dedicated smoke-control system. Thus in this case sprinkler system can contribute to the reduction of upgrade program cost (use of the existing HVAC system).
- In case of sprinkler protection, the user could make some limited changes to the composition of the fire load (i.e. add some pieces of furniture, install vending machines, etc.), which would not cause any variations of content's hazard.
- Even in case of faster growing fire (i.e. medium fire which rate of heat release of 1 MW could be reached 300.0 sec. after the ignition) properly functioning sprinkler would enable the proposed smoke management system to control the smoke spread for a time necessary to complete the occupant's evacuation.
- There is a higher reliability of an ordinary HVAC system over a specifically designed and purposefully built smoke exhaust system.

9. CONCLUSIONS

- Based upon fire simulation results, no significant fire safety benefits are provided by construction of second egress tunnel network when properly installed sprinkler and smoke exhaust systems are in place.
- In spaces occupied by multi-lingual population the proper evacuation of occupants can be assured only in case of engagement of staff efficiently trained in crowd-management.
- The way things stand at present, in spaces occupied by multi-lingual population, the effective way-finding facilities should be composed of traditional back-illuminated signs with the worldwide known word EXIT.

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