

# Fire safety: a short history in the Paris subway

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**ABSTRACT:** After a short presentation of the Paris Transport Authority (RATP), this paper describes the evolution of the objectives of the use of the natural and mechanical ventilation system during the last 30 years. According to the different regulations and guidelines used for safety in the road and rail tunnels in the world, it shows the methodology used and the difficulties to define the optimized system for cost and efficiency.

## 1. SHORT PRESENTATION OF THE RATP

The Transport Paris Authority (RATP) is a government-owned, industrial and business company, operating a dense and close knit network of metros, buses and tramways serving Paris and the Île de France region.

The RATP represents 446 stations or stopping points, 16 Metro lines representing 211.3 km, 2 RER lines (regional express railway lines) representing 115 km and a bus network with 312 lines representing 3325 km.

The underground Metro and RER lines are equipped with 317 high rate flow fans, over 769 escalators and over 360 airshafts.

Each weekday, 6 million journeys are carried out on the railway network and 3.43 million journeys on the bus network.

## 2. FIRE SAFETY IN TUNNELS AND UNDERGROUND STATIONS

### 2.1 General remarks

Not later than 1976, before the publication of the regulatory texts, the RATP had shown great concern with the fire safety question by implementing a study commission with the Paris Fire Department. The first consideration was to define the priority tools to be implemented in the field of fire prevention and rescue operations:

- Standards related to fitting materials for trains and stations, to cables...
- Smoke removal,
- Fire brigade accesses,
- Communication means,

- Setting up of links between the fire brigade and the RATP in terms of organisation and co-ordination in case of incident.

Besides these aspects, drills implementing a railway incident frequently coupled with smoke emission were carried out every second month so as to acquaint the firemen with the metro's underground environment as well as to validate the studies.

That is the reason why, later, in order to maintain an overall consistency of its systems in technical matters and operation conditions, the RATP was often compelled to disregard the regulations suggested in 1983 for the stations and train stations and in 1998 for the tunnels.

### 2.2 Current rules and regulations

Underground space is subjected to two complementary regulations: one concerns the stations or stopping points, the other the tunnels.

#### 2.2.1 Stations or stopping points

The 380 Metro stations and stopping points and the 66 RER stations are dealt as "GA class Public Receiving Establishments". As such, they are subjected to:

- the ministerial order of 20th February 1983 (Regulation specific to GA class (stations) establishments)
- the ministerial order of 25th June 1980 (Safety regulation against fire and panic hazards in Public Receiving Establishments) in the absence of specific rules included in the above specific regulation).

Moreover, to take into account the regulatory concept of chief of establishment or of establishment group, the stations and stopping points are generally set under the single authority

of a Line Manager. For connecting stations, a selection is made inside the company to define a line manager in charge, on the other hand, as far as third parties are concerned (department stores, French National Railways). The responsibility of managing the various premises is defined by a covenant between the various bodies specifying the geographic boundaries of the various areas.

To enforce article GA3 of the ministerial order of 20th February 1983, stations and stopping points are ranked in 5 (n°1 to n°5) classes according to the theoretical amount of public simultaneously present at the peak hour: more than 1500; 701 to 1500; 301 to 700; 201 to 300; less than 200.

For underground stations and stopping points, the operating company normally sets the amount of public but, in the case of the RATP, this is made by the Fire Safety Inspection according to specific criteria:

- booking hall: density of public = 1 person/2 m<sup>2</sup>
- interchange facility: density of public = 1 person/2 m<sup>2</sup>
- shops: density of public = 1 person/ m<sup>2</sup>
- platforms: maximum number of boarding or alighting passengers according to counts carried out at peak hours.

### 2.2.2 Tunnels

For the new-built (railway or underground) tunnels the interministerial directive n° 98-300 of the 8th July 1998 defines the construction and operation features to be implemented and the safety equipment to be installed to reach several basic targets:

- minimizing the probability for an incident to occur
- detecting abnormal conditions
- preventing and fighting fire
- allowing the protection and, in case of fire, the evacuation of passengers and the intervention of rescuers

For the renovated old tunnels, it is specified that “the feasibility of the measures of this technical order will be studied as the case may be”.

This technical order ranks tunnels according two criteria: the type of operation (city lines, mixed lines) and the length (0.8 to 5 km; 5 to 10 km).

A new standard related to the underground guided transportation systems is currently in preparation.

## 2.3 RATP current principles

### 2.3.1 Compartmentation and fire detection

The lack of compartmentation of public areas in stations, between tunnels, platforms and outside leads to a continuity of premises. For this reason those areas are not fitted with fire detectors, even in the case of intricate or deep stations, which, for three main grounds, are entitled by the regulation to be fitted with such detectors:

- those areas are generally subjected to important air draughts (up to 4 m/s) due to the combined or only action of train movements and natural or forced ventilation. It would therefore be illusive to believe to be able to determine the location of the ignition location accurately enough to implement relevant procedures of smoke removal and people evacuation
- the very fast dust clogging of fire detector triggers many false alarms, which cancel the credibility of the equipment.
- the presence of passengers, station employees and shops ensures fast fire detection.

The same applies to trains due to the presence of the driver and of passengers.

On the other hand, a conventional (ionic, optical...) detection is installed in premises or areas considered as hazardous, namely:

Escalator machine rooms, train stalling areas, shops, storerooms, transformer rooms providing electric power to stations, technical galleries and premises beneath platforms.

Except stores, which are connected to passenger areas, those hazardous premises are split from passenger areas by firewalls and doors.

### 2.3.2 Smoke removal

#### 2.3.2.1 Historical background

By the late sixties, the RATP initiated a large program of renewal of Metro rolling stock and of station equipment, resulting into a degradation of climatic conditions

To correct that, a large program of fan installation was launched which led to the installation of high rate flow fans.

Due to the short distance (600 metres) between adjacent stations, the ventilation concept implemented consists in building an extracting ventilation shaft at an equal distance from the two adjacent stations, the air intake occurring through the station accesses.

In the meantime, the RER (regional express railway lines) were built. The ventilation was integrated from the initial design. To optimise costs, the construction wells were installed at locations chosen to later ensure good ventilation.

Due to the long distance between stations and to the depth of the tunnels, the implemented concept consists in ensuring a longitudinal sweeping through a sequence of fans operated either in extraction or in intake.

In a few large stations specific comfort ventilation, with or without refrigeration or smoke extraction has been built.

#### *2.3.2.2 Proceeding to pass from comfort function to smoke removal function*

Structures were originally built to perform a function of comfort.

Due to the absence of regulation in the mid seventies, one of the first requirements was therefore to implement the existing comfort ventilation to ensure smoke extraction for fires occurring in tunnel or in station as well.

For this purpose, aeraulic tests were performed in all Metro and RER stations and tunnels. Simultaneously, simulations were made with 1D software.

After a few advanced validation tests, the comparison of results has shown the efficiency of those methods, in spite of discrepancies noticed for very intricate stations.

That is the reason why, in connection with the Paris Fire Department, it has been decided, for every alteration of the ventilation and for each new line, to carry out on-site tests to define the ventilation proceedings in case of fire.

Simultaneously, a full-scale test was performed in a specialized lab – INERIS – in order to assess the fire behaviour of existing fans. The test consisted

in dismantling an existing fan and to reassemble it in the lab.

The equipment was subjected to increasing temperature levels from 60°C to 250 °C by 20°C steps during one hour for each temperature level.

Those tests showed that the motor-fan set remained operational up to 250°C, however they highlighted the weakness of some components (punch-buttons, end-of-stroke contacts).

A replacement program of those weak components has been set up, which allowed to give the equipment a fire resistance of 200°C during 2 hours, enabling us to proceed from the concept of smoke extraction to that of smoke removal, in accordance with to the regulation.

#### *2.3.2.3 Smoke removal control*

The smoke removal control has been obtained through three actions:

- the development of a compendium of ventilation proceedings for each tunnel and station: the "operator's guide", which presently includes 579 areas.

According to the accurate fire location, this guide allows to know:

- the ventilation method to initiate and the various control locations,
  - the direction of smoke propagation and the quality of the smoke removal in relation to a four level scale (air flow speed: greater than 1.5 m/s; 1.5 to 1; 1 to 0.5; less than 0.5m/s)
  - the recommended station to evacuate passengers and to give access to the rescuers
  - the most common markers (signals, junction tracks, ventilation shafts) enabling to determine the location of the fire.
- a new test equipment to obtain warmer smokes, more similar to those of an actual fire, in order to validate proceedings.

Two pieces of equipment have been built thanks to subsidies from a European research project:

- a special car allowing to get a heating power of 1.5 MW and a smoke temperature of roughly 250°C at the

output. The design is based on concepts elaborated by the STCUM ( Metro of Montreal, Canada), and

- a portable equipment, made of several units weighing less than 80 kg, generating up to 500 kW, energized in DC or AC at various voltages to perform tests in station accesses or in technical premises
- the proposal of new means to improve passenger evacuation

Surveys have been carried out jointly with the Scientific and Technical Committee of the Building Industry in order to propose an air curtain system allowing isolating passengers from smokes in the very deep or too intricate stations.

Those surveys resulted in defining several unidirectional or bi-directional modular systems, matching any structure. Those devices have been implemented in several stations of the new-built METEOR line.

#### 2.3.2.4 Operations in progress

Several actions have been carried out to further improve the efficiency and the reactivity of the smoke removal:

- development of a ventilation software  
This new tri-dimensional tool, validated through tests on an aeraulic model, makes it possible to assess and validate the most relevant ventilation proceedings to ensure the smoke removal in tunnels and stations.
- the continuation of theoretical surveys jointly with specialised laboratories  
Studies related to smoke backlayering and stratification are carried out jointly with the Universities of POITIERS and of VALENCIENNES; they consist in realizing aeraulic models for several kinds of sources of fire, of obstructions (trains, tunnel equipment) and of tunnel shapes. At the same time comparisons are made with software surveys.
- the realization of a centralized fan control system

The latter action is aimed at reducing the starting delay of the fans and at saving those 2 to 3 minutes fundamental when treating a fire, to

avoid panic and to foster the right selection of the evacuation path in case of a fire in tunnel.

- the improvement of the smoke removal

A new target of smoke removal velocity has been set to 1.5 m/s in accordance with the new regulation of tunnels. A realization program is in progress, the first stage of which will concern the lines operated with pneumatic tyre rolling stock, which represent a more serious hazard.

### 2.3.3 Evacuation

#### 2.3.3.1 Stations

This is the major safety concern because this action consists in having people in a safe condition. During the construction of the Metro, between 1900 and 1920, the accesses were sized according to standards, which remain valid today. In 1983, when the regulation was set up more accurate rules have been formulated which generally remain in accordance with the past.

##### 2.3.3.1.1 Regulatory constraints

They set for the stations:

- the number of exits in a station: at least 2,
- the evacuation time: 10 minutes,
- the circulation speed of passengers: 1.4m/s at grade; 0.6 in staircases,
- the passenger rate of the pieces of equipment:

Doors	60 P/min
Corridors	100 P/min/m (in width)
Fixed staircases (up direction)	60 P/min/m (in width)
Fixed staircases (down direction)	75 P/min/m (in width)
Travelators	100 P/min
Escalators(up direction)	50 P/min
Escalators (down direction)	60 P/min
Three-rod turnstiles	30 P/min
Open toll gates	60 P/min

##### 2.3.3.1.2 RATP methods of implementation

Total evacuation time:

After much research a simple evacuation rule has been set up; it takes into account the total evacuation time by the formula:

*total evacuation time = walking time in normal condition + extra waiting time*

The walking time in normal condition is the maximum needed by a passenger to get from the platform to a safe area, by walking at regulatory velocities during his whole trip.

The extra waiting time is the greatest of the waiting times determined by the ratio “ public amount/ regulatory passenger rates ” for each piece of structure or equipment.

The selection of the amount considered is of primordial importance. For the Paris system we suppose the amounts hereunder:

- platforms: entering passengers + connecting passengers at the peak hour
- trains: 2 berthed trains loaded at 6 passengers/m<sup>2</sup>
- booking and interchange halls: 0.5 passenger/m<sup>2</sup> in booking halls and 0.25 passenger/m<sup>2</sup> in interchange facilities

In the stations, the smoke removal from accesses possibly filled with smoke is not taken into account in the assessment of evacuation times (however the failure of an escalator is taken into account). Of course, this approach is insufficient, and evacuation times are rather theoretical times used for a right sizing of heavy crowded passenger areas than actual evacuation times.

#### *2.3.3.2 Tunnel*

In case of fire on a train in a tunnel, it is highly recommended to bring the train into a station, the structure of which is sized to ensure passenger evacuation in the best possible conditions. In most cases this requirement is complied with by inhibiting the emergency brake (UITP recommendation). Consequently dwelling and evacuation in tunnel are quite exceptional.

##### *2.3.3.2.1 Regulatory constraints*

They are only related to the size of the side path in a tunnel and the step height between the train floor and the pathway.

##### *2.3.3.2.2 RATP rules, criticism*

In case of evacuation in a tunnel, passengers get onto the track by means of ladders installed at each door against the tunnel wall; this means seems to be preferable to a specific gangway, which poorly allows to cross or to overtake passengers. Besides, even if the tunnel is difficult to be walked, its

whole width can be used beyond the area of the dwelled train. The assessment of the evacuation time is difficult because it depends on the number of passengers and on the visibility and toxicity conditions of the surrounding smoke.

#### *2.3.4 Rescue intervention*

Unquestionably, fire fighting is within the competence of the fire brigade, which are posed many and various problems by this: searching and evacuating victims, uneasy access, presence of toxic smoke, and so on.

The RATP initiated several actions to help them in their task:

- improving intervention means

Specific fire brigade entrances have been realized where existing or new-built stations are more than 800 m apart. Those overpressurised premises are fitted with dry pipes and communication means (self-energized phones).

Similarly dry standpipes have been installed with fire plugs every 100 m, allowing to get water in a shorter time on new-built lines or on hazardous sections.

At last, extra-light trolleys make it possible to carry more rapidly extinguishing and rescue equipment onto the site.

- co-ordination procedures

Due to the difficulties to be overcome in case of fire, it is necessary to specify the functions of all those who possibly could intervene.

For this purpose, a plan (general instruction n°449) was set up as soon as the early eighties to define the commanding, acting, and co-ordinating procedures between the RATP managers and the commander of rescue operations of the fire brigade who is in charge of commanding all the public rescue departments in case of a serious event. The simultaneously initiated crisis communication plan (general instruction n°465) is aimed at ensuring an efficient communication with media, and, above all, at performing the welcoming and information of victim families. It is worth to notice that those measures, taken very upstream the regulation, served as a model in other domains.

- drills

Human errors can make physical measures in matter of prevention and of fire fighting inefficient. A prevention effort is needed in this domain too.

For this purpose, 8 as realistic as possible drills are set up each year, 5 of them occurring in a tunnel. Most of them are set up during the night traffic ban with release of cold smokes; one of these drills, said "major drill" because it involves the implementation of many means: fire brigade, first aid, police, psychological unit. To date more than 80 training drills have already been performed.

### 3. PREVENTION

An effective prevention involves three mutually complementary actions: the choice of fitting materials to minimize hazards, safety inspections and feedback.

#### 3.1 Choice of fitting materials

##### 3.1.1 Trains

The most restrictive standards are related to the trains. French standards NF16101, 16102, and 16103 define the fire behaviour of materials, which leads to M and I classification, smoke opacity and toxicity leading to F classification.

Then, selection rosters are set up which make it possible to match up criteria. It can be noticed that, the better the smoke release index, the worse the fire reaction index. As a reference for Metro rolling stock, the targets are eventually:

Materials for ceilings	M0 F0
inner fittings	
side walls	M1 F1
lighting fitments	M1 F1
curtains	M1 F1
seats	M1 F1
floors	M1 F1
Materials for outer fittings	M2 F1
Cables	
inside	AF1

##### 3.1.2 Stations and stopping points

The regulation does not limit the amount of non-combustible or non-combustible materials implemented but imposes restrictive conditions in relation to the amount of chlorine and of nitrogen contained by volume unit of the area where they are implemented.

This difficulty is overcome by a very wide use of M0 and M1 ranked materials (floors, wall coatings, and furniture)

A peculiar effort has been made for cables, consisting in CR1-C1 halogen-free, RATP specific qualities.

#### 3.2 Periodicity of security inspections

The ranking of stations and stopping points rules the periodicity of security inspections:

- classes 1 and 2: every second year
- classes 3 and 4: every second year
- class 5: every fifth year

As far as shops are concerned, the periodicity is that of the station where they are located.

These inspections include the verification of public open areas, of safety equipment, of evacuation controls (doors, anti-fraud gates, etc.), the knowledge check of station employees and the check of information documents.

Further to the inspection a report is drafted and delivered to the manager in charge in view of possible correcting actions.

#### 3.3 Feedback

The return of experience is the feedback loop allowing learning lessons from any incident. This is the necessary implement to improve operating safety and dependability.

This action involves the setting up of REX (Return of Experience) clubs, of various meetings to raise the awareness of employees, and of a dedicated structure able to extract the quintessence of all these works.