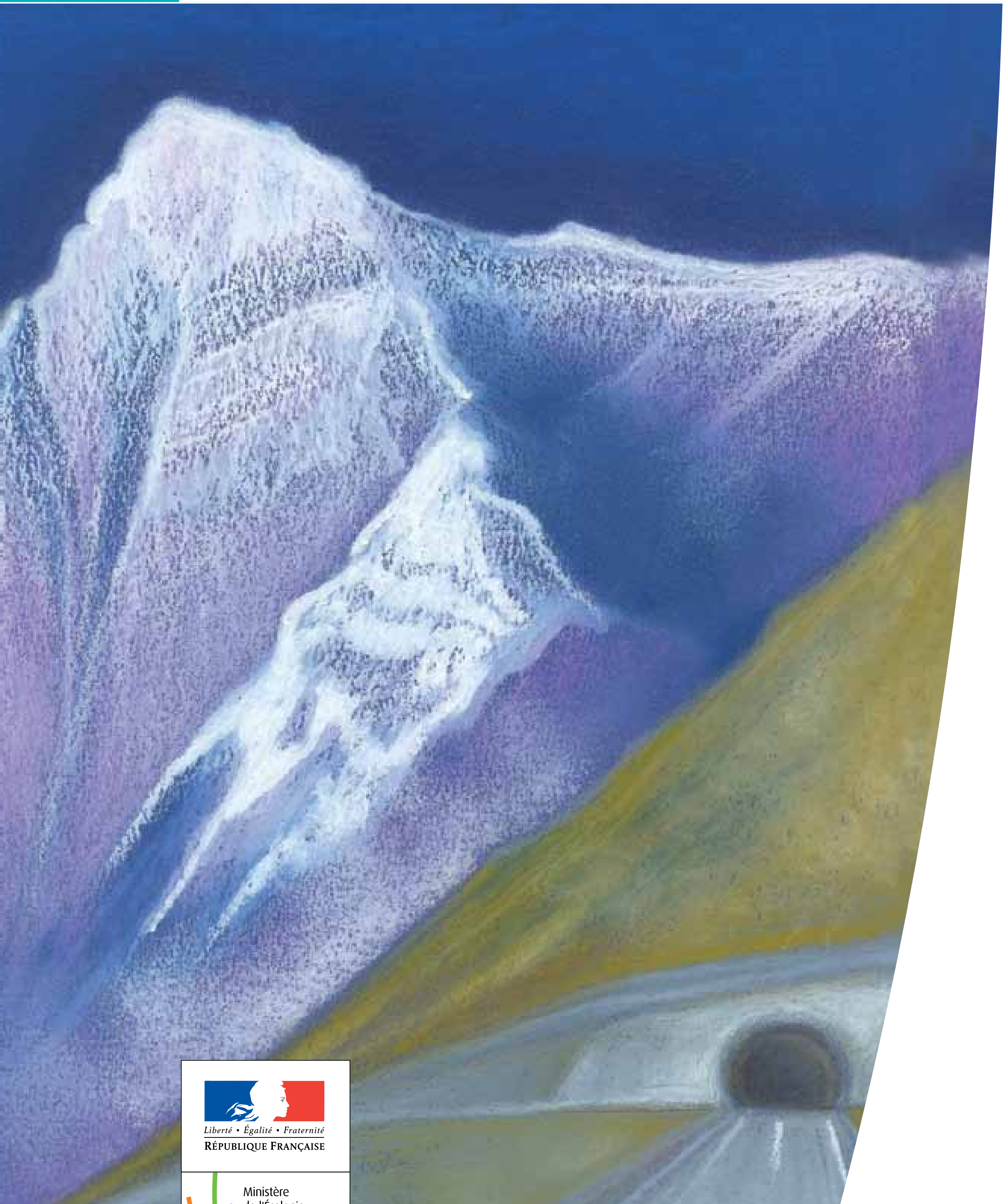
Guides

ENVIRONMENTAL STUDIES IN ROAD PROJECTS "AIR" AND "HEALTH" SECTIONS

THE SPECIFIC CASE OF TUNNELS



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October 2011

Centre d'Études des Tunnels

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THE SPECIFIC CASE OF TUNNELS

October 2011

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INTRODUCTION

For crossing natural obstacles or improving the integration of road projects, especially in urban areas, tunnel construction is a pertinent solution. The question of their possible impacts should nevertheless be raised, particularly in relation to air quality.

This guide proposes a methodology for studying the impact of tunnels on air quality when drawing up road plans, at the initial study stage. The study phases considered here are feasibility and preliminary studies through to preparation of the impact study and the inquiry file preceding the declaration of public utility.

Article L122-3 CE of the *French Environmental Code [30]* specifies that an impact study comprises at least *"a description of the project, an analysis of the initial status of the area liable to be affected and its environment, a study of the project's impact on the environment or human health, including combined impacts of other known projects, proportional measures planned to prevent, reduce and where possible, compensate for significant negative impacts of the project on the environment or human health as well as a presentation of the main arrangements for monitoring these measures and their effects on the environment or human health".*

Since tunnels constitute very localised sources of pollution, which is not immediately diluted, the presence of local residents who would be constantly subject to these nuisances is justification for considering the air quality in the vicinity of these structures.

In many cases a specific study does not need to be carried out before the declaration of public utility. These are the most frequent cases, and the main aim of this guide is to give road planners who are not tunnel specialists the means for detecting them. For such cases, the guide provides the project designers with factors enabling them to explain why an issue is slight, as the lack of a specific study does not mean the public are not informed about the project and the justification for it.

In other cases a tunnel project may be sensitive, and a specific study must be carried out. In such cases this guide offers an appropriate methodology for each development phase of the project, from feasibility studies to the study of the option proposed at the public inquiry.

For later study stages, and for studies in the "project" phase in particular, please see the *Guide for considering air quality of the vicinity of road tunnels [2].*

The present guide was written for use in the context of new tunnel or cut-and-cover projects. Although old tunnels are not specifically tackled, the methodology set out here may be adapted to them quite easily, such as a situation in which major works require an impact study to be carried out for example.

This document may be considered as a specialised supplement to the *Methodological Note* [(1)] *on the assessment of the effects of air pollution on health in road impact studies of February 2005 [3] and its Technical Appendix [4],* published by SETRA and CERTU.

Like these two documents, this guide is an aid to application of the principles laid down in the *French Environmental Code [30]*, *implementing circular n° 98-36 of 17 February 1998 [1], decree n° 2003-767 of 1st August 2003 amending decree n° 77-1141 of 12 October 1977 on impact studies [6], the Ministry of Health circular of 3 February 2000 on the guide to reading and analysing the health section of impact studies [7], and the Ministry of Health circular of 11 April 2001 on analysing effects on health in impact studies [8].*

This guide was written by a working group formed by CETU, SETRA, CERTU, the CETE de Lyon and the Mediterranean CETE, with contributions from CEREA.

(1) This Note is in the process of revision. Its future development might require appropriate implementation of this guide, during its consequent updating.

1. TUNNELS AND THEIR VENTILATION

1.1 IMPACT OF ROAD PROJECTS ON AIR QUALITY: WHY STUDY TUNNELS SPECIFICALLY?

Air pollution produced by a road tunnel is identical to that caused by all roads. A tunnel does not create pollution. The total quantity of pollutant emissions, largely proportional to the number of vehicles and the distance covered, remains the same, tunnel or no tunnel.

The possible tunnel impacts on emission volumes are therefore minimal, limited to the consequences of any change in traffic conditions (speed of vehicles or longitudinal profile) and in general favourable (avoidance of crossing a mountain pass with heavy demands on engines for example).

Although tunnels have little impact on emissions, they do have an impact on concentrations, as they generate more localised pollutant discharges, while allowing sensitive areas to be avoided by judicious choice of route. This is why tunnels should be studied specifically.

1.1.1 A two-fold issue: indoor and outdoor air

A tunnel is a semi-confined space inside which dilution is less than on open roads. This leads to higher pollution levels above the roadway and an accumulation of pollution at the tunnel exits.

A study of a tunnel's air quality should therefore evaluate pollution levels both inside the tunnel and in its immediate surroundings.

1.1.2 Air inside tunnels: a study carried out after the declaration of public utility, at the Project stage

A detailed study of concentration levels inside tunnels does not come within the scope of studies prior to the public utility inquiry since, in all cases, technical solutions can ensure low levels of indoor pollution are achieved without the feasibility of the project being called into question for lack of an appropriate solution.

A simple preliminary dimensionning of the fresh air ventilation is carried out at this stage, but the detailed study is carried out when the Structure Plans are drawn up. Its purpose is to design the tunnel's ventilation system so as to ensure good air quality inside the tunnel, in accordance with the rules (see the CETU *"Ventilation" Master File* [9]).

In the initial study stage it should however be possible to find out the main characteristics of the pollutant discharge (quantity emitted and speed of ejection), from which impacts on the ambient air can be assessed.

1.1.3 Air outside tunnels: a criterion to be taken into account in the initial study stage for some complex projects

In the phases preceding the declaration of public utility, the presence of a tunnel in a road project may lead to a specific study of its impact on the air quality of its immediate surroundings.

Route studies should of course have the primary objective of achieving a solution providing a gain in terms of air quality. More precisely, the solution should be such that the quantities of pollutants emitted near sensitive zones in the absence of a tunnel are, as a result of the tunnel, discharged in non-sensitive, or at any rate less sensitive places (usual scenario of tunnels in urban environments).

But discharges in sensitive areas cannot always be avoided. In some cases it may be necessary to undertake a specific study, to check the feasibility of the project, i.e. ensure that impacts are acceptable, and to provide factors for comparing variables and to justify the choices made. This guide proposes a simple methodology for carrying out such studies.

1.2 THE DIFFERENT TYPES OF COVERED ROADS, DEFINITION OF A TUNNEL

The purpose of this guide is to provide a method for assessing the effects caused by the channelling of pollutant emissions which occurs when a road is not in the open air.

All structures which contribute to this pollution channelling phenomenon are dealt with in this document, in which the term "tunnel" has a very wide meaning. It refers to all covered roads, regardless of their method of construction and position in relation to the natural terrain. They may be bored tunnels, immersed tunnels, cut-and-cover tunnels or roads covered by roofs with no openings. The construction site stage of these structures may have impacts on air quality, particularly dust generation, which are not dealt with in this guide. To deal with this question, please see the CETU *"Environment" Master File* [11].

Partial covers that have openings over 1 m² in area per traffic lane and per linear metre(2) (air gaps for example) are not mentioned here, as their behaviour is very similar to that of open air structures.

Partial roof coverings which have openings of less than 1 m² per traffic lane and per linear metre are not dealt with in this document either because, while they cannot be considered in the same category as open structures, their air behaviour is not the same as that of tunnels. A number of elements presented here may however be transposed without difficulty to the study of such structures.

1.2.1 Bored tunnels

Strictly speaking, tunnels are underground structured bored into the ground. The choice of boring technique is related to the geology and geotechnical characteristics of the site, but also takes into account external constraints such as the presence of homes which could steer it towards techniques that minimise nuisances in the construction phase.

There are many boring methods (see the *CETU "Civil Engineering"* Master File *[10]*):

- some of the simplest methods include boring with explosives, very efficient in all rocky terrains, excavation by roadheader machine, a vehicle constituting an arm with rotating head fitted with drilling and excavating tools, or even just spades and hydraulic hammers;

Photo 1 - Excavation by traditional method

- on poor quality land more sophisticated techniques have to be used. Either the characteristics of the terrain must be improved in situ (drainage, injection, freezing, etc.) to give it a better intrinsic quality before excavation or retaining structures must be built (bolting the front of the tunnel, constructing a pre-vault, etc.);
- about thirty years ago rotary digger shields appeared. These machines were designed to provide a wide range of functions from excavation to laying the final surface. Very effective in loose terrain, their use grew very quickly.

Photo 2 - Rotary digger shield excavating the Mont Sion tunnel (A41)

(2) Definition given by the Technical Instruction of 25 August 2000 [13]

1.2.2 Cut-and-cover tunnels

Cut-and-cover tunnels differ from bored tunnels by their method of construction, which is not underground but in the open air: the excavations are generally carried out in the open air.

Cut-and-cover tunnels are mainly built in urban areas in order to reduce sound pollution and to restore the continuity of the urban fabric. They are possible when the longitudinal profile of the project reveals a small covering over the vault and the site is free of any construction.

Cut-and-cover tunnels are sometimes simply the result of covering existing roads.

Once in use the aeraulic function of cut-and-cover tunnels is for the most part identical to that of tunnels, with discharge into the atmosphere at a few localised points (portal and extraction vents).

Photo 3 - Cut-and-cover tunnel under construction (Toulon Underpass)

1.2.3 Immersed tube tunnels

For under-river or under-sea crossings the immersed tube tunnel technique can be used. This consists of laying tubes, usually rectangular in section, on the river or sea bed.

Photo 4 - Tubes under construction

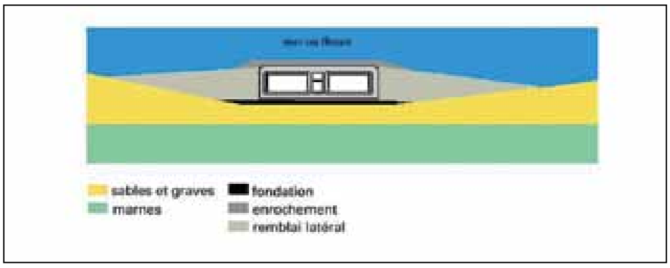


Illustration 1 - Immersed tubes banked up on the sea or river bed

The advantage of this technique is that it provides the shortest-length solution as the opening is situated on the river bank or seashore. But this advantage can turn into a disadvantage if there are heavy land use constraints in the spot planned for the opening. This technique sometimes also has the disadvantage of reducing the draught available for shipping.

1.3 ACCIDENTS

Largely due to their rarity, accidents have a very limited impact on the external air quality and the health of local residents. The only exception is accidents involving the Carriage of Dangerous Goods by Road (ADR) which result in the release of toxic gases. This point is dealt with under risk analysis studies (cf. booklet 3 of the CETU *Guide to Road Tunnel Safety Documentation* [12]).

The safety of users is covered in the *French Highway Code (Section I Chapter VIII) [25]* and several supporting texts that specify the administrative and technical arrangements to be implemented in road tunnels over 300 metres in length.

Of these texts, the *Technical Instruction of 25 August 2000 [13]* specifies in detail and subject by subject all the technical provisions to be provided (civil engineering provisions, safety equipment, behaviour during a fire and operation). Although applicable by law only to new national tunnels, it constitutes the technical reference document used for specifying the safety level of existing national tunnels and for local authority tunnels, both new and existing.

The safety document (cf. the *CETU Guide to Road Tunnel Safety Documentation* [12]) is a key document. It brings together all documents, descriptions and studies essential to a proper understanding of the operation and safety of the structure at each stage of its life.

1.4 METHODS OF DISCHARGING POLLUTED AIR FROM TUNNELS

The specific feature of tunnels compared with open air roads is the existence of localised discharges of polluted air. Three discharge points can be distinguished:
- tunnel portals,
- extraction systems,
- possible openings in the fabric of the structure.

1.4.1 Tunnel portals

Portals, sometimes also called heads, form the entrance and exit of the tunnel. They are natural discharge points for pollutant emissions from tunnels when no specific system has been put in place. When slip roads are connected to a tunnel, their free end constitutes a portal in its own right.

Illustration 2 - Discharge of pollution through tunnel portals

Air discharges through portals are complex and dispersion is more or less rapid depending on the configuration of the site. In urban areas, exits in tunnel approaches, trenches, or between the walls of adjacent buildings ("street canyons") are unfavourable conditions for good dispersion, under certain wind conditions. This type of discharge generates more risks of high concentrations in urban areas.

1.4.2 Extraction systems

Depending on the case, extraction systems taking air from the tunnel to the outside are designed to be used:
- only for smoke extraction in the event of a fire,
- only for extracting polluted air during normal operation,
- both for smoke extraction and for extraction of polluted air.

Generally, extraction systems are provided for safety in relation to fires, in order to remove smoke from the tunnel.

More rarely, extraction systems are used to prevent excessive air velocity in tunnels, or to limit the amount of pollutants released through tunnel portals when these are located in very sensitive places.

At the end of the extraction system there is generally a stack, called a ventilation stack, extraction stack or discharge stack.

Illustration 3 - Discharge of pollution through a ventilation stack

In urban areas and where there are nearby homes, stacks may need to be quite high in order to raise the height of the pollution plume and reduce its impacts.

Stacks are always combined with a mechanical ventilation system which may be longitudinal or transverse. (cf. 1.6.2). They can be used in all types of tunnel, including cut-and-cover tunnels.
The location and height of stacks, as well as the discharge speed, must be studied in order to ensure appropriate dispersion of the discharged pollution.

The decision to build a ventilation stack must be taken before the public inquiry, so that this feature is made known to the public and written into the declaration of public utility.

However, at the stage of studies prior to the declaration of public utility, stack height and discharge velocity may not be the subject of in-depth studies, as these require very precise ventilation dimensionning. At this stage the height of a stack should not be underestimated where later changes might put the project in danger of failing to comply with the declaration of public utility document. For the same reason, when a unit is provided for the purpose of smoke extraction, any desire to retain the possibility of changing its use with a view to extracting pollution, even intermittently, must be mentioned in the impact study.

Architectural and landscape studies included in the tunnel design phase may lead to good integration of ventilation stations and associated extraction systems. An example of integration in the urban environment is given in the photograph below, for the UV2 ventilation unit in the Toulon tunnel.

Photo 5 - the UV2 ventilation unit in the Toulon tunnel

1.5 OPENINGS

In the case of tunnels close to the surface, pollutants may be discharged naturally from the tunnel to the atmosphere through openings in the walls, without recourse to mechanical means. Besides forming an outlet for pollutants, openings allow fresh air to enter the tunnel.

These may for example be air gaps, sound checkerboard areas, or a succession of cut-and-cover tunnels separated by short open-air sections.

Illustration 4 - Discharge of pollution through air gaps

Openings are arranged laterally or in the ceiling; their configuration and siting must be studied so as not to create unacceptable local pollution, while including all related aspects, particularly acoustic aspects.

Real air gaps capable of continually removing polluted air should be distinguished from "fire" air gaps, which are closed during normal operation and only opened in the event of a fire. These are however used less and less, as in the absence of any mechanical means of ventilation enabling the forced extraction of smoke, there is no guarantee that opening them will have any beneficial effect. Another disadvantage is the lack of reliability of these heavy and rarely manoeuvred systems, which must however be kept in excellent state of mobility in case of need.

1.6 VENTILATION SYSTEMS

1.6.1 The role of ventilation

The purpose of ventilation in tunnels, under normal operating conditions, is to ensure pollution levels are low:

- inside the tunnel, by diluting the pollutants emitted;
- outside the tunnel, by contributing to a reduction in concentrations (see the *"Ventilation" Master File [9]).*

This is fresh air ventilation.

Ventilation also has an essential role in the event of fire, firstly to protect users from smoke while they are being evacuated, and then to enable the emergency services and fire services to intervene. This is smoke extraction ventilation. This document, which has the aim of dealing with impacts of tunnels on the environment from the point of view of air pollution, is not interested in ventilation in the event of fire. This subject, which is covered by very specific regulations, should be studied in detail during the phases that follow the declaration of public utility.

In the case of mechanically ventilated tunnels, smoke extraction requirements are often key. System performance therefore goes beyond the strict needs of fresh air ventilation. In normal operation this margin can be used to ensure compliance with environmental constraints from the point of view of air quality, even in extremely unfavourable pollution scenarios far more pessimistic than design hypotheses. In such cases, a drop in concentration levels inside the tunnel can be achieved through the ventilation alone, when the pollution sensors placed inside the tunnel measure excessive levels. This margin for manoeuvre can also be used to reduce the levels in the area around the tunnel. In this case the difficulty lies in identifying these critical situations in the absence of permanent sensors outside the tunnel. We will see later that by using simple methods an approximate link can be established between the level of concentration at the tunnel exit and the level at a given distance (see 5.3).

1.6.2 Types of tunnel ventilation

The most commonly used types of ventilation are discussed in the following paragraphs.

1.6.2.1 Natural ventilation

Natural ventilation is when no dedicated mechanical ventilation system is installed in a tunnel.
The two main factors that contribute to natural ventilation by creating a longitudinal air flow are:

- the piston effect caused by the traffic (air flow in the direction of the traffic) and an increase in levels of turbulence;
- weather conditions at each of the portals, or to be more precise, the differences in weather conditions between the two portals (atmospheric pressure, temperature or wind) which may be the cause of significant air flow in a tunnel.

By definition, natural means of ventilation are not controlled by the tunnel operator. They are sufficient only to dilute pollutants in the case of short tunnels.

1.6.2.2 Longitudinal mechanical ventilation

The longitudinal system consists of pushing the air mass in the tunnel towards the outside, with no contribution of fresh air other than through the portals. Waste air is nearly always removed directly through the portals. Occasionally, this is supplemented by point extraction (mass extraction) systems.

Illustration 5 - Longitudinal system (the arrows indicate the movement of air)

The thrust is created by jet fans, positioned on the underside of the tunnel roof.

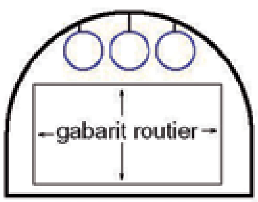


Illustration 6 - Example of fans positioned on the underside of the tunnel roof

1.6.2.3 Transverse mechanical ventilation

The transverse mechanical ventilation system consists of injecting and / or extracting air at regular intervals in the tunnel. A pure transverse system is when the extracted flow is equal to the injected flow, a semi-transverse system is when there is no extraction of polluted air or insufficient injection of fresh air, and a partial transverse system is when the extraction flow is less than the injected flow (the precise terminology of the different transverse ventilation systems is given in the *"Ventilation" Master File [9])*.

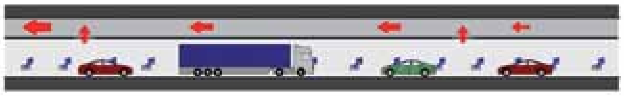


Illustration 7 - Transverse system (the arrows show the movement of air, fresh air in blue, polluted air in red)

Transverse mechanical ventilation generally requires the installation of ventilation ducts to blow fresh air in and extract polluted air. These ducts may be positioned on the roof, under the roadway or along the walls.

1.6.2.4 Examples of sections across transversally ventilated tunnels:

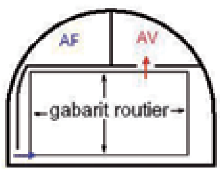


Illustration 8 - Ceiling ducts (AF = fresh air, AV = polluted air)

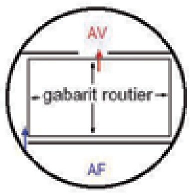


Illustration 9 - Fresh air duct under the roadway and polluted air duct in the ceiling

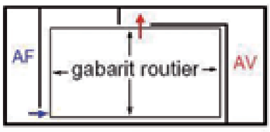


Illustration 10 - Lateral ducts

For this type of ventilation, fans are often placed in one or more ventilation units (cf. Glossary and list of acronyms) situated at the end of fresh air and polluted air transit ducts. Sometimes, in the case of cut-and-cover tunnels, fans are placed directly on the ceiling, at extraction or injection vents regularly spaced throughout the length of the structure. In this case, there are no ventilation ducts.

1.6.3 Choice of type of ventilation and consequences on the location of discharge

To study the impact of a tunnel on air quality, it is necessary to know the location of discharge, and this depends on the type of ventilation (cf. 1.6.2).

At the initial stage of road studies, precise ventilation studies on tunnels have not necessarily been carried out and it is therefore not always possible to refer to them. In order to deal with the issue of tunnels in impact studies, the following general principles and consequences resulting from them can however be accepted:

> **In most cases, tunnels of less than 300 metres in length are not mechanically ventilated, relying solely on natural ventilation.**
In the case of a tube less than 300 metres long inside which traffic travels in just one direction, discharge may be considered to be entirely located at the exit portal (downstream portal) driven by the piston effect. In the ordinary case of a tunnel comprising two one-way tubes, emissions are considered to be divided between each tube exit portal, i.e. between the two sides of the tunnel.
In the case of two-way traffic in a single tube, the simplifying assumption is that discharges are divided equally between the two portals, when the survey period is long enough to cover varied conditions affecting the air (traffic and weather).

> **For longer tunnels requiring mechanical ventilation, the design of the ventilation system is based on the maximum use of the piston effect created by the movement of vehicles.**
For tunnels with one-way traffic this principle often leads to the selection of a longitudinal system, which may directly reinforce the piston effect, if this is insufficient. Discharge can then be considered to be entirely located at the vehicle exit portal. Over a certain length it may however be necessary to use an extraction stack to maintain acceptable pollution levels in the tunnel. A certain amount of discharge occurs around the stack.
In the case of one-way traffic, the urban nature of the

tunnel may however lead to the selection of a transverse type of ventilation, better adapted to smoke extraction when there are risks of congestion and therefore a traffic jam at the source of a fire. In this case, as an initial approximation, it can nevertheless be assumed that the direction of air flow in the tunnel is determined by the piston effect, and that therefore discharge is entirely located at the vehicle exit portal, which in turn leads to the assumption that emissions are distributed between each exit portal, and therefore between the two sides of the tunnel, in the usual situation of one tube per traffic direction.

> **Safety rules often require the use of the transverse type of ventilation in the case of two-way traffic.**
> When the traffic in a tube is two-way, the choice of ventilation system is closely related to the urban or non-urban nature of the tunnel. In the case of urban tunnels over 300 metres in length and longer non-urban tunnels, a transverse ventilation system is required, essentially for the purpose of smoke extraction.
> For all cases of two-way traffic, regardless of the ventilation system envisaged and provided that extraction is not provided for health reasons, a simple assumption can be made that discharge is distributed equally between the two portals, when the survey period is long enough to cover the various conditions that affect the air (traffic, weather).

The general principles outlined above constitute a very simplified approach. For a more detailed consideration of ventilation, please see the ventilation rules specified by the technical instructions appended to French circular 2000-63 *[13]* for tunnels over than 300 metres in length, which are also given in the *"Ventilation" Master File [9].*

1.7 THE TREATMENT OF AIR IN TUNNELS

Air purification is a solution often put forward to reduce the impacts of discharge from tunnels. It seems even more appealing as the polluted air is already channelled by the tunnel or in extraction ducts.

Two types of purification must be distinguished according to the nature of the pollutants:
- filtration, which applies to particulate matter and smoke,
- chemical or biological processing for certain gaseous pollutants considered the more harmful of those contained in vehicle emissions, such as oxides of nitrogen for example.

Smoke filtration in tunnels is a technique that has been implemented for some thirty years in Japan where it is used to ensure good air quality in some tunnels which have a small injection flow, and in Norway where there are particular pollution issues linked to abrasion of the roadways by studded tyres. Filtration nevertheless remains a cumbersome and onerous solution. There are only about sixty tunnel filtration systems in the world.

The processing of gaseous pollutants in tunnels is more recent. There are not many of these in the world and those there are, are often experimental.

For more details, please see the CETU note *"The treatment of air in road tunnels - state-of-the-art of studies and work" [16].*

Such techniques may constitute ancillary solutions, given that just by using of one or more extraction stacks, without purification, the impact of discharge can be reduced sufficiently, even in the most difficult cases.

1.8 SOME RULES TO BE LEARNT

1.8.1 The effects of ventilation on concentration levels in tunnels

The air flow velocity and pollutant concentration in a tunnel are related to the ventilation system. How they change according to distance from the entrance portal is shown in the following paragraphs[3].

NOTATIONS USED

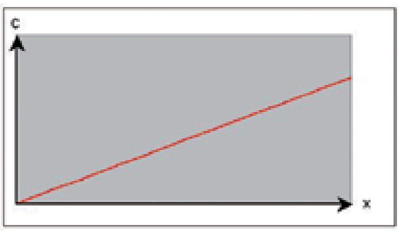
- *e: Average emission of a certain pollutant per vehicle (in quantity emitted per second)*
- *n: number of vehicles per tunnel kilometre*
- *V: air velocity (m/s)*
- *C: concentration in quantity of pollutant per cubic metre of air*
- *S: section of tunnel (m²)*
- *x : distance in kilometres from the tunnel portal through which fresh air enters*
- *L: Length of the tunnel*
- *V_0: air velocity at the portal through which air enters*
- *q: mechanically injected flow (m³/s/km)*

1.8.1.1 Longitudinal ventilation

As there is neither extraction or injection, air velocity is constant throughout the tunnel: $V = V_o$.

Longitudinal profile of air velocity

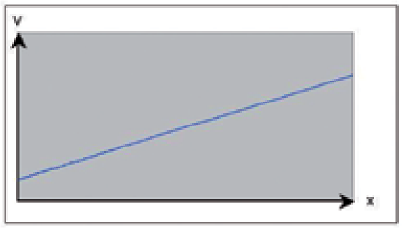
The pollutant concentration is: *C = e.x.n / V.S*



Longitudinal profile of pollutant concentration

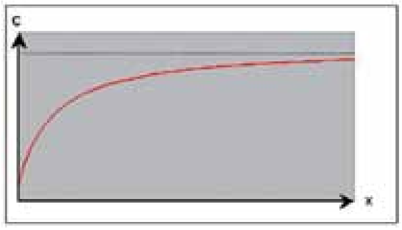
1.8.1.2 Semi-transverse ventilation without inversion of the air velocity direction[4]

Fresh air enters through one portal and through air supply vents arranged at regular intervals. At the other portal the polluted air has a velocity $V = V_0 + (q.L/S)$.



Longitudinal profile of air velocity

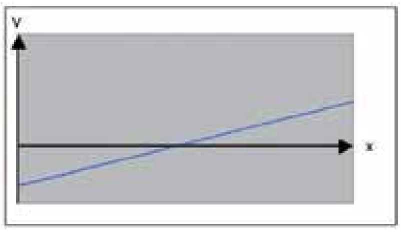
The concentration tends towards a maximum limit value $C_{max} = e.n / q$.



Longitudinal profile of pollutant concentration

1.8.1.3 Semi-transverse ventilation with inversion of the air velocity direction

Polluted air exits through the two portals, the concentration is constant: C = e.n / q



Longitudinal profile of air velocity

Longitudinal profile of pollutant concentration

(3) The concentration of fresh air entering the tunnel is assumed to be negligible

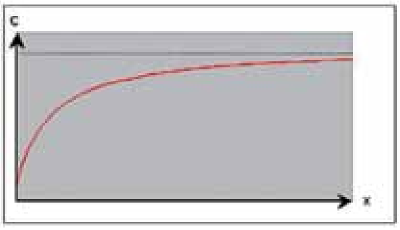
(4) Whether or not the air flow in the tunnel is inverted depends on the extent of atmospheric counter pressure and the piston effect caused by the traffic.

1.8.1.4 Pure transverse ventilation (when longitudinal air velocity is not zero)

Injection and extraction flows being equal, the longitudinal air velocity is constant: $V = V_o$.

Longitudinal profile of air velocity

The concentration tends towards a limit value $C_{max} = e.n / q$.



Longitudinal profile of pollutant concentration

Extraction only has a limited effect on dilution, its main role is to change the velocity of the air flow.

1.8.1.5 Pure transverse ventilation (when longitudinal air velocity is zero)

The concentration is constant, $C_{max} = e.n / q$; the extraction has no effect on dilution, its sole role is to cancel out the longitudinal air flow.

1.8.2 Aeraulic independence of successive tunnels

When ventilation problems arise in the design phase of a tunnel, the first solution is to see whether it is possible to reduce its length, in order to reduce tunnel emissions and consequently discharge concentration.

This solution is however frequently impossible to implement, and an attempt may then be made to divide the tunnel into a succession of several shorter tunnels.

In the case of tunnels of less than 300 metres in length, they are generally considered aeraulically independent when the uncovered length between the two covered sections is about a hundred metres.

1.8.3 Central dividing walls

Central dividing walls are built as extensions from the ends of tunnels to prevent the recirculation of polluted air. They can be used where there are two parallel one-way tubes to prevent polluted air discharged at the end of one tube penetrating inside the other tube under the piston effect due to vehicles.

They are usually about forty metres long.

Their height is at least equal to that of the roof of the tunnel but it depends on the environment. To prevent air moving from one tube to another an alternative to the central dividing wall is offsetting the portals by 30 to 50 metres.

Photo 6 - Offset portals – Uriol tunnel on the A51 motorway

Photo 7 - Central dividing wall – Landy cut-and-cover tunnel – A1 motorway (Seine Saint Denis)

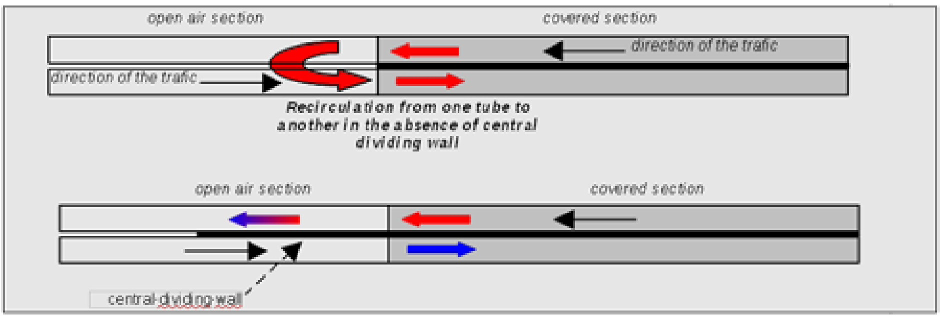


Illustration 11 - Effect of central dividing wall

2. INITIAL STUDIES

Before a decision is made to carry out a road infrastructure project its economic, social and environmental benefits must be demonstrated. If this benefit is demonstrated, the process of developing the route is undertaken in several successive stages. At the end of each of these, the level of precision of the future route is refined, in respect of technical, environmental, social and economic constraints.

Throughout this process all aspects of air quality must be taken into account, from the most global (global greenhouse effect or regional photochemical pollution) during discussions on the project's benefits, to the most local (direct impacts of pollution on health, vegetation or the built environment) when the study area is reduced to a study strip of a few hundred metres, or much less.

The obligation to take account of air quality, which has been a major environmental concern for several years, was reinforced when the French *Law on Air of 30 December 1996 [5]* came into force. As well as being mandatory, studying a project's potential impacts on air quality is essential for the contracting authority to be able to answer the many questions that will be raised throughout the project's development. The study procedures actually leave a large part of the discussions and the consultation with the authorities, elected representatives, associations, residents and users, all of whom are nowadays aware of the issue of atmospheric pollution.

When a tunnel is present in a road proposal, it is liable to cause particular impacts from the point of view of pollution dispersion (cf. 1.1), and should therefore be given suitable consideration, or even subjected to a specific study.

This chapter, which gives a basic description of the successive phases in the development of a road project, states the issues for each phase in terms of atmospheric pollution linked to tunnels and how they should be tackled. The term initial studies covers feasibility studies and preliminary studies, through to the development of the impact study and the inquiry document that precedes the declaration of public utility.

Public contracting authority road and motorway tunnel design plans, whether they belong to the national, departmental or local road network, are subject to the French *MOP law [17].* On the French national road network, the *circular of 7 January 2008 laying down the arrangements for drawing up, investigating, approving and assessing national road network investment operations [18]* supplements the MOP law, by specifying the steps to be followed in drawing up plans, while emphasising requirements in terms of quality and formalisation of the order or financial statements.

For a detailed analysis of the content of these two texts and their impact in terms of tunnel design please see the CETU *"Studies Guide" [19]*.

It will be accepted that the most helpful texts for understanding and implementing this guide are:

- *law 85-704 of 12 July 1985 [17],* known as the MOP law, on public works contracting and its relations with private contracting;
- the *circular of 7 January 2008 specifying arrangements for developing, investigating, approving and assessing national road network investment operations [18],* which amends and partially replaces the *circular of 27 October 1987 [20] on motorway projects under private management,* and annuls the *circular of 5 May 1994 [21] on national road network projects not under private management;*
- the *circular on the conduct of large national infrastructure plans of 15 December 1992 [22]* and the *Barnier law of 2 February 1995 [23];*
- *circular n°2004-63 Public Works and Ecology of 22 November 2004 on cooperation between the environment and the public works departments in drawing up and investigating road projects for the national network [24] ;*
- the French *highway code [25],* section I, chapter VIII, on the safety of road network structures whose operation presents special risks to human life;
- the *law of 10 July 1976 [26],* clarified by the *decrees of 12 October 1977 [27], 25 February 1993 [28]* and *the 1st August 2003 [6],* which introduces the impact study (5);
- the *French Environmental Code [30],* and in particular its *article L122-3,* the contents of which were clarified by the *circular of 17 February 1998 [1];*
- *the Health-Public Works-Ecology circular of 25 February 2005 on the consideration of the impacts of air pollution on health in road infrastructure impact studies.*

In the rest of this document, the vocabulary used is that of the MOP law, as it has a more general scope than the circular of 7 January 2008. The three successive stages of studies carried out before the public inquiry are therefore shown under the names "feasibility studies", "preliminary studies - comparison of options" and "preliminary studies - study of the proposed option".

(5) in the context of the Grenelle 2 law, an in-depth reform of the impact study system is underway; the reader should refer to these texts when published

2.1 FEASIBILITY STUDIES

2.1.1 Reminder of objectives

Without going into details of the objectives specified in the texts listed above, readers are merely reminded that the first studies undertaken should enable the contracting authority to give an opinion on the feasibility of the project from the economic, social and environmental stand points.

At this stage, the feasibility of the project is discussed with the support of studies carried out by the contracting authority, which must apply a multimodal approach to all the major functions of the infrastructure.

2.1.2 Substance of the discussion and parties involved

In the case of larger projects, of national interest, the *"Barnier" law of 2 February 1995 [23],* supplemented by the *decree of 10 May 1996 [29],* created the French National Public Debate Commission (CNDP), with very wide representation from : members of parliament, elected local representatives, associations, members of the Conseil d'État and members of administrative tribunals and courts of justice. The discussion organised by this body must expressly concern all the socio-economic issues and significant impacts on the environment.

For other government projects, the *circular of 15 December 1992 [22]* specifies the framework for the discussion, known as the "Bianco" debate, between the contracting authority and political, social, economic and association leaders, under the responsibility of a coordinating prefect. A discussion monitoring committee, consisting of external experts, is set up. At the end of the discussion specifications are drawn up and published by the government.

2.1.3 The issues in terms of air quality and tunnels

At this stage, discussions on projects frequently give rise to numerous questions on the potential impacts of a tunnel from the point of view of atmospheric pollution. These questions for the most part come from political and association leaders, whether residents, farmers, vine growers or nature protection associations.

To answer these questions the contractor may rely on a collection of bibliographic data (regional air quality plans or regional climate, air and energy guidelines, urban transport plans, atmospheric protection plans, reports of measurements taken by approved air quality monitoring associations, etc.).

This data is generally sufficient to provide relevant answers at this stage, except in certain cases, such as long urban tunnels, which may represent particularly significant issues in terms of air quality. In these cases, while trying to use the existing bibliographical data to the maximum, it may be helpful to provide more detailed answers by undertaking studies such as "Preliminary Studies" beforehand.

It will be accepted that the main difficulty at this stage lies in communication, as very precise answers need to be given (cf. 5 - The content of feasibility studies), although there is still considerable uncertainty regarding the physical and technical characteristics of the project. It is during the later stages that studies will be refined, as they progress (notion of progressiveness), in order to construct the project.

2.2 PRELIMINARY STUDIES

2.2.1 Objectives

Preliminary studies [6] have four objectives:

- drawing up the preliminary programme which lists the contractor's needs, constraints, data and requirements, and enables an appropriate and reliable definition of the main characteristics of the operation to be made;
- checking the technical and financial feasibility of each option in accordance with the preliminary programme;
- proposing a preferred solution in order to launch the public inquiry;
- drawing up the pre-operation financial assessment.

While drawing up the draft programme is a continuous process which progresses throughout the preliminary studies, the study of each option and the study of the option proposed at the public inquiry constitute, in the sense of the issues dealt with in this document, two distinct study phases which occur one after the other. In the rest of this document they will be called "comparison of options" and " study of the proposed option" respectively.

2.2.2 Preliminary studies: comparison of options

2.2.2.1 Substance of studies, parties involved and documents drawn up

Within the study area, the contracting authority starts by collecting technical, economic and environmental data.

To support this data various route options are studied as well as junction options with the rest of the network (crossroads, interchanges and distribution roads). The level of precision for presentation of the project is in the order of 1/10,000.

An environmental and socio-economic comparison of the options is carried out by consultation with local representatives.

This phase leads to preparation of the comparison of options sub-file of the preliminary studies. At the preliminary studies phase, each tunnel of each option must be the subject of specific studies, in order to check its technical feasibility and to draw up the preliminary financial assessment.

(6) Or "studies preceding the public inquiry" according to the French circular of 7 January 2008

The special structure study drawn up in this way for each tunnel enables several solutions to be compared from the technical and financial stand points. At this stage technical considerations mainly relate to civil engineering aspects (geology, excavation and retaining techniques) and the geometrical specifications of the structure including the position of the portals. From the point of view of ventilation, the study is still quite cursory. It mainly consists of specifying the ventilation system to be selected and of making a preliminary calculation of size aimed at providing all the necessary characteristics for specifying the transverse profile. At this stage it is necessary to see whether ventilation stations should be provided and, where appropriate, to consider possible sites for them.

2.2.2.2 Issues in terms of air quality

The comparison of options covers a number of environmental topics. Air quality, like hydrology, natural environments, landscape integration, noise, agriculture, hydrogeology, town planning, the living environment or architectural conservation, is one of these.

In order for air quality to be differential criterion, a sufficiently detailed study must be carried out. Data collection should go beyond a bibliographical synthesis. In the first place, in situ measurements should be taken, as initial pollution levels are factors to be taken into account in the selection of a study strip. Then, in order to compare the options with each other, quantified indicators must be constructed; these are usually:

- quantities of pollutant emissions,
- public exposure to pollution,
- crop exposure to pollution.

The specific nature of tunnels must be taken into account in these calculations. The study method may nevertheless remain simple and didactic, as, at this stage, it is a matter of comparative work (cf. 6 - The content of preliminary studies - comparison of options).

Even though strictly speaking it is the study strips that are compared with each other, the contracting authority frequently draws up a reference route (in plan, longitudinal profile and transverse profile). Because of this, the air quality study may rely on a route that includes a fairly precise definition of the geometry and position of the tunnels, and of their portals in particular, even though they are of course likely to change during later study phases.

2.2.3 Preliminary studies: study of the proposed option

2.2.3.1 Objective

Once the proposed study strip for the public inquiry has been chosen, the corresponding reference route, designated by the term "proposed option", must be studied in detail in order to assess the foreseeable socio-economic and environmental impacts.

The study of the proposed option, which follows the comparison of the previously drawn up options, is used to draw up the impact study, which will constitute the technical support file for the inquiry preceeding the declaration of public utility.

2.2.2.1 Substance of studies, parties involved and documents drawn up

At this stage a detailed study must be made of the potential impacts of building the project within the study strip selected at the end of the previous phase.

Even though the route is not fixed in the study strip, its definition is refined in relation to the comparison of options stage. The scale for presentation of project maps and plans is generally 1/5,000, and sometimes even 1/2,500 in urban areas.

The final preliminary studies file includes the comparison of options and the study of the proposed option sub-files. A special study report is drawn up on difficult sites for each tunnel of each option and in all cases for each tunnel of the proposed option.

Even though this file is essentially technical it should allow clear conclusions, easily understandable by non-specialists, to be drawn. In fact, it will be used as the basis for drawing up the impact study, which will be widely distribution among the authorities, MPs, residents and users, as a part of the inquiry preceding the declaration of public utility.

2.2.3.3 The issues in terms of air quality

At this stage of the studies, it is by definition no longer possible to reason in comparative terms, since details are given for one particular solution.

Possible impacts of the project should be estimated: estimation of concentrations, comparison with statutory thresholds, assessment of the population concerned, etc, while ensuring that the level of detail in the study remains proportionate to the sensitivity of the project. Care should be taken to ensure the complexity of tools used is consistent with the project definition (cf. 7 - Content of preliminary studies - study of the proposed option).

Dispersion modelling tools may be used, provided they satisfy two conditions: they are appropriate and simple, and their results are reliable and easy to use in terms of communication to non-specialists, in the context of the impact study. One should never lose sight of the fact that one of the major issues is to make what are often technical factors accessible to the largest number of people, and in this respect, the non-technical summary of the impact study is an essential tool.

3. RULES AND POLLUTANTS TO BE CONSIDERED

3.1 AIR INSIDE AND OUTSIDE TUNNELS: TWO SEPARATE REGULATIONS

The regulations or recommendations in matters of atmospheric pollutant concentrations, in underground structures and in the ambient air, essentially aim to ensure acceptable levels of concentration for the community, in the short and long term.

In tunnels, recommendations also include the fact that gaseous pollutants may have impacts on the comfort (air gaps and odours) and safety (visibility distance) of users.

Where health is concerned, the risks for an individual are closely linked to the amount of pollutant inhaled, i.e. the product of pollutant concentration in the air breathed in during exposure to this pollution. As time spent, and consequently exposure time, is shorter in tunnels, acceptable levels are higher there than in the outside air.

Reference concentration levels therefore vary between the inside of the tunnel and its surrounding area.

This two-fold reference constitutes a real difficulty for the consideration of tunnels in road studies. Not only are the acceptable levels not the same, but they are also calculated over different lengths of time and expressed in different units.

The main pollutants discharged by cars are gaseous pollutants, the toxic effects of which depend on concentration and length of exposure time. Of particular concern are carbon monoxide (CO), oxides of nitrogen (NOx) and hydrocarbons (HC). Vehicles, especially diesel vehicles, are also the source of the emission of very fine particles, with diameters in the order of a few micrometres.

3.2 AIR OUTSIDE TUNNELS: THE FRENCH LAW ON AIR AND ENVIRONMENTAL CODE AS REFERENCE TEXTS

The *Law on Air [5],* the provisions of which are reiterated in articles L.220-1 et seq. of the Environmental *Code [30],* requires air quality to be monitored across the whole of French territory.

3.2.1 Pollutants monitored: decree n°2002-213

Decree *n°2002-213 of 15 February 2002 [31],* which supplements *the Law on Air [5],* specifies the list of pollutants that should be monitored. There are seven of them:

- carbon monoxide,
- sulphur dioxide,
- nitrogen dioxide,
- particulate matter (PM10 (7) and PM2.5(8))
- lead,
- ozone,
- benzene.

The alert thresholds and limit values not to be exceeded for each of these pollutants, all monitored by the network of approved air quality monitoring associations (AASQA) are laid down by this decree.

Each threshold corresponds to a concentration with limited effects on human health or vegetation. For health, these are taken from the recommendations of the World Health Organisation (WHO) and epidemiological studies.

3.2.2 Threshold application principle

For each pollutant, several acceptable thresholds are given, depending on the period over which the threshold is calculated, the aim being both to monitor and to regulate:

- peaks of pollution (level not to be exceeded over a short period or level that may only be exceeded very selectively over a long period of observation);
- the average levels encountered from day to day (average levels calculated over a long period).

The observation periods laid down by the decree of *15 February 2002 [31]* vary from an hour to a year.

(7) Particles of less than 10 µm in diameter.
(8) Particles of less than 2.5 µm in diameter

3.3 AIR INSIDE TUNNELS: ACCEPTABLE LEVELS

For a long time carbon monoxide was the criterion for fresh air ventilation dimensionning in tunnels. Today however, considering the significant reduction of carbon monoxide emissions, it is now based on nitrogen oxides (NOx) and opacity.

3.3.1 French Ministry of Health Circular 99.329

The French Law on Air contains no requirement on acceptable levels of concentration in tunnels, or even more generally on levels within enclosed or semi-enclosed underground structures.

The principle reference on toxic pollutants for underground structures is *French circular 99.329 of 8 June 1999 [32].*This specifies following the recommendations given by the French High Council on Public Health (CSHPF) in its report *"Air quality in underground or covered structures" [33]* issued on 14 December 1998.

3.3.2 CETU's ventilation master file

In order to ensure good visibility conditions, the *CETU "Ventilation" [9]* master file specifies a threshold not to be exceeded for opacity. By regulating this parameter, the risk of an accident due to poor visibility should be avoided and a feeling of comfort and safety for users maintained. The opacity threshold has therefore not been laid down according to health criteria. The opacity regulations nevertheless constitute a means of limiting concentrations of smoke and fine particles harmful to health.

3.3.3 The technical instruction of 25 August 2000

In an incident or accident situation, the technical instruction of 25 August 2000 gives thresholds not to be exceeded for carbon monoxide and opacity.

3.3.4 Pollutants monitored

The pollutants monitored are firstly the two pollutants subject to the regulations in *circular 99.329 [32]*:

- carbon monoxide,
- nitrogen oxides (through nitrogen monoxide or nitrogen dioxide),

and secondly, particulate matter, by measurement of opacity.

Carbon monoxide concentrations are now much lower than twenty years ago due to renewal of the car fleet. Its monitoring is therefore no longer a health issue.

Due to the difficulty of continuously measuring nitrogen dioxide, *circular 99.329 [32]* proposes to measure nitrogen monoxide instead and to apply a conversion coefficient. Today however, measurements in tunnels show that it has become difficult to apply a reliable conversion coefficient, as the NO_2 / NO ratio fluctuates considerably, with very high levels of NO_2. For this reason the measurement of NO_2 could quickly become an issue that has to be addressed, at least in the most heavily used tunnels.

3.3.5 Threshold application principle

As exposure times in underground structures are in principle short, the limits not to be exceeded are calculated over fairly short periods (15 to 30 minutes at most), or even quite simply expressed as a momentary threshold not to be exceeded. For more details please see the *"Ventilation" master file [9].*

3.4 POLLUTANTS TO BE SELECTED FOR IMPACT STUDIES

3.4.1 Impact studies

For all projects subject to an impact study, *article L122-1 of the Environment Code [30]* requires their effects on air quality and on human health to be studied.

For road projects the substance of studies to be carried out in this context is laid down by the *circular of 17 February 1998 [1].*

This circular was been supplemented by the *methodological note on the assessment of the effects of air pollution on health in road impact studies [3].*

This methodological note gives a list of pollutants that should be taken into account in road project impact studies [9].

In all cases, the following eight pollutants should be taken into account:

- nitrogen oxides (nitrogen monoxide and nitrogen dioxide),
- carbon monoxide,
- hydrocarbons,
- benzene,
- particles emitted with exhaust,
- sulphur dioxide
- nickel,
- cadmium.

While these pollutants should be considered in an impact study, they need not all be studied in detail at the various stages of the study. They should be selected according to the type of project and its surrounding environment. For example, sulphur dioxide, which is practically no longer emitted by road traffic will only be studied if other very heavy sources of this pollutant are present in the vicinity of the project.

It should be noted that for level 1 studies as defined by the *methodological note [3]*, the list of pollutants specified above is extended to other substances. The complete list of pollutants to be considered in order to assess the health risk is as followings:

- standard pollutants: sulphur dioxide, carbon monoxide, nitrogen dioxide, particles from vehicle exhaust,
- volatile organic compounds: benzene, 1.3-butadiene, acetaldehyde, formaldehyde, acrolein,
- polycyclic aromatic hydrocarbons : benzo(a)pyrene,
- metals: arsenic, barium, cadmium, chromium, mercury, nickel, lead.

(9) The methodological note is currently being revised which could result in changes to the list of pollutants

3.4.2 Pollutants to be taken into account in the case of tunnels

The first principle to adopt when considering tunnels during the initial phases of road projects is a principle of consistency with the rest of the air quality study.

In fact, at this stage, as stated earlier (cf. 2 - Initial studies), the impacts of a road route in which a tunnel is present should be assessed, but an in-depth study of the tunnel should not be carried out, this will come later (in the Project stage).

As the regulatory framework consists of statutory law, decrees and circulars, the preliminary study will specifically assess the same list of pollutants for the effects of tunnels as those considered for the impact study (cf. 3.4.1 - Impact studies), apart from carbon dioxide which will not be the subject of special examination, as the presence of a tunnel does not change the effect of this global pollutant in any way.

In practice, a basic list of pollutants to be taken into account can be drawn up specifically for tunnels in road projects in the stages preceding the declaration of public utility.

This list will include four pollutants:

- carbon monoxide,
- nitrogen dioxide,
- smoke or "particulate matter",
- benzene,

The first three pollutants (carbon monoxide, nitrogen dioxide and smoke or "particulate matter") are included in the list of those that should be studied in road project impact studies and also regulated and measured in tunnels. They are therefore not to be ignored.

Benzene should also be studied, as, although it is not one of the pollutants usually monitored in tunnels, it has nowadays become a major concern in terms of air quality monitoring, due to its acknowledged effects on human health and the fact that it frequently exceeds the statutory levels to which it is subject in the vicinity of traffic lanes.

As the project progresses this list could change from one study phase to another along with the methodologies used. For more on this, please see chapters 5, 6 and 7 of this guide, which deal with feasibility studies, comparison of options (preliminary studies) and the study of the proposed option (preliminary studies) respectively.

3.5 THE LINK BETWEEN OPACITY, SMOKE AND PARTICULATE MATTER

In tunnels, the term "smoke" is currently used to mean particulate pollution, but due to very different measuring techniques, the smoke observed in tunnels differs markedly from the particulates generally monitored in ambient air.

In tunnels, particulate pollution is not measured directly (in mass, number or volume) but indirectly, through opacity. Opacity is defined as the attenuation of a light flow crossing an air column. It is expressed in m^{-1}, and the recommended maximum opacity is $K = 5.10^{-3}\ m^{-1}$ under normal operating conditions. This corresponds to an attenuation of 10 % of the light intensity over a distance of 20 metres.

When measuring opacity all particulates are considered, but in the case of ambient air only particulates of small diameter are observed (particulate matter PM 10 (10) and PM 2.5 (11)).

It is very difficult to establish a match rule between opacity and particulate matter concentrations (PM10 for example).

Twinned measurements of opacity and particulate matter concentrations carried out in several European countries show that equal opacities do not correspond to identical concentration levels, as the type of opacimeter, calibration of light by the opacimeter and the spectrum of the particle diameter being measured come into play.

To assess the PM10 concentrations in discharge at a tunnel portal, it may first be considered that the inside of the tunnel is at the admissible threshold ($K = 5.10^{-3}\ m^{-1}$), even though this is pessimistic since this threshold should normally never be exceeded.

Then, in order to go from opacity to particulate matter PM10, the match (12):

$$10.10^{-3}\ m^{-1} \Leftrightarrow 1000\ \mu g/m^3\ (PM10),$$

can be considered, which leads to a value of 500 µg m³ being taken, if positioned at the acceptable threshold. Moreover, comparative measurements have shown, for total PMs, a match of (13):

$$4.7.10^{-3}\ m^{-1} \Leftrightarrow 1000\ \mu g/m^3\ (PM).$$

These values by default permit, in first approximation, an order of size of concentrations to be obtained (overestimated), with the later possibility of carrying out more precise and less pessimistic calculations if it is observed that the statutory thresholds are approached or exceeded.

In fact, the transition coefficient between particulate matter and opacity depends on the tunnel and the type of traffic using it. In a tunnel heavily used by heavy goods vehicles carrying pulverulent materials, for example if it is situated near a quarry, particles will be large. Inversely, particles will be smaller in regularly cleaned tunnels used by traffic consisting mainly of cars.

Further information on this subject is given by the "Road Tunnel" report: vehicle emissions and air requirements for ventilation" *[34]* published in 2004 by the Committee on road tunnels organised by the World Road Association (PIARC).

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(10) particles of less than 10 µm in diameter
(11) particles of less than 2.5 µm in diameter
(12) see CETU's Ventilation master file
(13) see CETU's Ventilation master file

3.6 NITROGEN OXIDES

The term "nitrogen oxides" covers nitrogen monoxide (NO), nitrogen dioxide (NO_2) and nitrogen tetroxide (N_2O_4).

Nitrogen dioxide is the one most frequently found in the ambient air, as nitrogen monoxide is rapidly oxidised to nitrogen dioxide. Nitrogen monoxide is moreover thought to be about five time less toxic than nitrogen dioxide [(14)]. For these reasons nitrogen dioxide is selected as one of the pollutants to be studied.

Obtaining nitrogen dioxide concentrations from vehicle emissions is not however direct, as emissions are given in nitrogen oxides.

In the main nitrogen oxides leave vehicle exhausts as nitrogen monoxide, but nitrogen monoxide then tends to oxidise in the air, and the NO/NOx ratio to decline over time and with increasing distance from traffic lanes. The chemical reactions involved in this transformation are complex, and some of them can only begin in the presence of natural light (ultraviolet rays).

The behaviour of nitrogen oxides is therefore very different inside a tunnel and in the area around it. In tunnels, the oxidation of nitrogen monoxide is very limited and this gas remains preponderant. In its *recommendations [33]*The French High Council on Public Health recommends using the ratio:

$$NO / NO_2 = 10, \text{ or } NO_2 / NOx \approx 0.1.$$

Recent measurements in tunnels have shown, however, that the NO_2/NOx ratio was tending to increase. Ratios of 0.2 or even 0.5 or more have been noted, confirming a trend observed not just in tunnels [(15)] .

Outside tunnels, the NO_2 / NOx ratio increases with distance away from the point of discharge. Accurately calculating changes in the NO_2/NOx ratio is very tricky, in view of the large number of parameters involved (geometry, solar radiation, temperatures, background pollution, etc.).

At CETU's request, the Atmospheric Environment Teaching and Research Centre (CEREA) developed a simplified model to calculate the NO_2/NOx ratio, depending on position in relation to the tunnel portal. The modelling method is described in report 2004-19 *"Estimation of average NO_2/NOx ratios near the mouth of a cut-and-cover tunnel in an urban area" [35]*, a summary of which is given in the Appendix.

(14) see toxicology sheet FT 133 of the French National Research and Safety Institute

(15) see the report of the French Agency for Health and Safety of the Environment and Work (AFSSET) relative to "The impact of post-purification technologies on NO_2 emissions from diesel vehicles, and associated health aspects" of 11 August 2009.

3.7 UNITS OF MEASUREMENT OF POLLUTANTS

Concentrations of gaseous pollutants may be expressed in two ways:

- in mass concentrations (µg/m³ for example),
- in volume concentrations or by volume (parts per million – ppm, or parts per billion – ppb).

The first is the one most commonly used for ambient air, the second being often used for underground structures.

Conversion from one unit to another is performed using the gas constant equation.

This equation is written:

$$W_i = \left(\frac{R_m \cdot T_u}{P_u}\right) \cdot \frac{K_i}{M_i} \cdot 10^6$$

NOTATIONS USED

- *Wi: volume concentration of a gas i in parts per million (ppm),*
- *Mi: molar mass of gas i (kg/kmol),*
- *Ki: specific concentration of gas i (kg/m³),*
- *Rm: gas constant (8314.3 Nm/(kmol.K)),*
- *Tu: ambient temperature (K),*
- *Pu: atmospheric pressure (bar, with 1 bar ≈ 105 Pa).*

Application of the transformation formula therefore requires the temperature in Kelvin and pressure at the project site to be known.

It should be noted that for temperatures around 20° C, a variation of 3° C only results in a 1% variation of the temperature expressed in Kelvin.

By fixing the temperature and pressure, the transformation equation becomes:

- for "normal" conditions described by p_u = 101 325 Pa and T = 273 K (0°C),

$$W_i\,(\text{ppm}) = 22{,}401\ .\ \frac{Ki}{M_i}\left(\frac{mg / m^3}{kg / kmol}\right)$$

- for "standard" conditions described by p_u = 101 325 Pa and T =298 K (25°C),

$$W_i\,(\text{ppm}) = 24{,}453\ .\ \frac{Ki}{M_i}\left(\frac{mg / m^3}{kg / kmol}\right)$$

Table *1* gives the correspondence between mass concentrations and volume concentrations for the usual pollutants [16] .

gas	molar mass (g/mol)	"normal" conditions conversion factors (101 325 Pa, 0°C)	"standard" conditions conversion factors (101 325 Pa, 25°C)
carbon monoxide	28	1 ppm = 1.25 mg/m³ 1 mg/m³ = 0.800 ppm	1 ppm = 1.14 mg/m³ 1 mg/m³ = 0.873 ppm
nitrogen monoxide	30	1 ppm = 1.34 mg/m³ 1 mg/m³ = 0.747 ppm	1 ppm = 1.23 mg/m³ 1 mg/m³ = 0.815 ppm
nitrogen dioxide	46	1 ppm = 2.05 mg/m³ 1 mg/m³ = 0.487 ppm	1 ppm = 1.88 mg/m³ 1 mg/m³ = 0.532 ppm
benzene	78	1 ppm = 3.48 mg/m³ 1 mg/m³ = 0.287 ppm	1 ppm = 3.19 mg/m³ 1 mg/m³ = 0.313 ppm

Table 1 - Correspondence between mass concentrations and volume concentrations for common pollutants

(16) for tunnels situated at altitude, average atmospheric pressure at the altitude of the tunnel should be taken into account (see also the CETU "Ventilation" master file)

3.8 SUMMARY TABLE OF REGULATORY OR RECOMMENDED LEVELS

Table *2* gives the regulatory or recommended levels for the pollutants on the list given in paragraph 4.2.

When no indication is given in the table, the values are relative to the protection of human health. Thresholds for protection of ecosystems are indicated.

pollutant	environment concerned	parameter	observation time	regulatory or recommended level		reference
carbon monoxide	underground structures	in exceptional situations, at any point in the tunnel	instantaneous value	**150 ppm**	*[171 mg/m³]*	technical instruction of 25/08/00
		average content over the entire length of the structure	15 minutes	**90 ppm**	*[103 mg/m³]*	circular of 08/06/99
			30 minutes	**50 ppm**	*[57 mg/m³]*	circular of 08/06/99
	ambient air	threshold value	average over 8 hours	*[8 ppm]*	**10 mg/m³**	decree of 15/02/02
nitrogen dioxide	underground structures	average content over the entire length of the structure	15 minutes	**0.4 ppm**	*[752 µg/m³]*	circular of 08/06/99
	ambient air	alert threshold	hourly average	*[0.21 ppm]*	**400 µg/m³**	decree of 15/02/02
		recommendation and information threshold	hourly average	*[0.11 ppm]*	**200 µg/m³**	decree of 15/02/02
		threshold value	99.8* centile over the calendar year of average hourly values	*[0.11 ppm]*	**200 µg/m³**	decree of 15/02/02
		threshold value	annual average	*[0.021 ppm]*	**40 µg/m³**	decree of 15/02/02
		quality objective	annual average	*[0.021 ppm]*	**40 µg/m³**	decree of 15/02/02
nitrogen oxides	ambient air	limit value (protection of vegetation)	annual average	*[0.016 ppm]*	**30 µg/m³**	decree of 15/02/02
particle matter opacity	underground structures	in exceptional situations, at any point in the tunnel	instantaneous value	**9.10^{-3} m^{-1}**	*see paragraph 3.5*	technical instruction of 25/08/00
		in exceptional situations, at any point in the tunnel	instantaneous value	**5.10^{-3} m^{-1}**	*see paragraph 3.5*	recommendation
particulate matter PM10	ambient air	threshold value	90.4* centile over the calendar year of average daily values	*[5.10-4 m-1]*	**50 µg/m³**	decree of 15/02/02
		threshold value	annual average	*[4.10-4 m-1]*	**40 µg/m³**	decree of 15/02/02
		quality objective	annual average	*[3.10-4 m-1]*	**30 µg/m³**	decree of 15/02/02
benzene	ambient air	alert threshold	annual average	*[1.6 ppb]*	**5 µg/m³**	decree of 15/02/02
		quality objective	annual average	*[0.6 ppb]*	**2 µg/m³**	decree of 15/02/02

Table 2

Value in bold: statutory or recommended value

[Value in square brackets]: converted value for "standard" temperature and pressure conditions (25°C, 101 325 Pa)

** value to be complied with 99.8 % of the time, i.e. which may only be exceeded for 18 hours in the 365 day calendar year*

** value to be complied with 90.4 % of the time, i.e. which may only be exceeded for 35 days in the 365 day calendar year*

4. EVALUATION TOOLS, INITIAL STATUS OF THE HEALTH RISK

This chapter outlines the stages to be followed in air quality studies for road projects, from drawing up the initial status to assessment of health risks.

The four successive stages of the study are as follows:

- characterisation of the initial status,
- determination of emissions quantities discharged by the tunnel,
- modelling the pollutant dispersion,
- health study.

The *methodological note [3]* gives recommendations on the content of each of these stages, which varies according to the level of the study. Four study levels, numbered I to IV, from the fullest to the simplest, are specified. The study level is determined according to the expected traffic by the project's planning horizon (according to homogeneous sections of over 1 km) and the population density in the project study strip.

Table *3* gives the general criteria selecting the study level for road projects. For more details please see the *methodological note [3]*.

The gradation of studies according to the extent of the project results from the application of the rules and regulations.

The *decree of 12 October 1977 [27]*, implementing article 2 of the law of 10 July 1976 [26] on nature conservation, specifies the content of impact studies. It indicates that this content should be proportionate to the extent of the planned work and developments and their anticipated impact on the environment. The *decree of 1st August 2003 [6]* specifies €1.9 M as the threshold above which an impact study is mandatory (17). Article 3 of the *decree of 12 October 1977 [27]* gives specific details on the requirement for an impact study procedure: it indicates that maintenance and large scale repair work, regardless of the structures or developments to which they relate, are not subject to this type of procedure (17).

This chapter presents the evaluation tools to be used at each stage of the study. Chapters 5, 6 and 7 specify how they are to be implemented.

T: traffic by the planning horizon of the project d: population density in the study band	T ≤ 10000 veh/d or T ≤ 1000 pcu/h	10000 < T ≤ 25000 veh/d or 1000 < T ≤ 2500 pcu/h	25000 < T ≤ 50000 veh/d or 2500 < T ≤ 5000 pcu/h	T > 50000 veh/d or T > 5000 pcu/h
no buildings	IV	IV	III	III
d < 2000 pop / km²	III if $L_{project}$ ≤ 50 km or II if $L_{project}$ > 50 km	II	II	I
2 000 < d < 10 000 pop / km²	III if $L_{project}$ ≤ 25 km or II if $L_{project}$ > 25 km	II	II	I
d < 10,000 pop / km²	III if $L_{project}$ ≤ 5 km or II if $L_{project}$ > 5 km	II	I	I

Table 3 - Study level according to traffic and population density

(17) In the context of the Grenelle 2 law, an in-depth reform of the impact study regime is in progress; the reader should refer to these texts when they are published

4.1 DRAWING UP THE INITIAL STATUS

4.1.1 Aims

Whether the development includes a tunnel or not, the initial status of the "air" must deal with several topics. These topics are as follows:

- air quality,
- soil quality,
- emissions inventory,
- meteorological data,
- topographical data, rugosity and buildings,
- population data,
- health indicators.

The initial status report should describe the issues, assess the sensitivities and define the constraints in the absence of any development project, so that after the studies, the impacts of the project options can be studied by comparison with this reference situation.

The purpose of the analysis of the initial status is:

- firstly, to describe the environmental quality of the study area from data known at the time of the environmental study, and the prospects of change up to the date of completion of the project;
- secondly, to supply reference information that will be used to assess the project's impacts on the environment.

This information must be researched at the impact study stage, but collection of this data should have been started during the preliminary studies, even though, at this stage, technical details concerning the exact definition of the project are sometimes lacking.

The study report entitled *"Road infrastructure impact studies, "air" and "health" sections - Initial status and data collection" [37],* published in February 2009 by CERTU, describes in detail the essential elements during this study phase. For more details please also see Chapter 10 of the *technical appendix to the Methodological Note [4]*.

4.1.2 Content by topic and sources of information

4.1.2.1 Air quality

From the point of view of air quality, the initial status strictly speaking consists of an estimate of pollution levels in the areas where the tunnel portals and, where appropriate, their ventilation units are to be sited. Air quality along the route of the tunnel should be assessed before it is put into service, with a view to establishing a "zero" status.

The initial status enables the pollution to be assessed at a given point once the project has been completed, by adding the levels of pollution due to the tunnel, calculated during the later study phases, to the levels of concentration measured in the initial status.

Depending on the degree of sensitivity of the study area and depending on the data available, the analysis of the initial status in relation to "air" could be based on pre-existing data or require specific data collection.

To use existing data, the main sources are:

- the Air Quality Monitoring Network (RSQA) and its Approved Air Quality Monitoring Associations (AASQA),
- Air Quality Data Base (BDQA),
- Regional Climate, Air and Energy Guidelines (SRCAE) which will replace the Regional Plans for Air Quality (PRQA),
- Urban Transport Plans (PDU),
- Atmospheric Protection Plans (PPA),
- Urban Road network Documents (DVA).

If the data cited above either does not exist or is insufficient, specific measurement collections must be carried out in situ, using analysers, passive diffusion tubes or plant bioindicators for example. In order to be able to make proper use of such data collection campaigns the weather conditions experienced during the measurement periods must be known. Wind speed and direction data can sometimes be obtained from a fixed weather station, but these stations are often some distance from the measurement site and it is therefore preferable to make provision for such equipment in addition to the pollution measurement device.

Mobile measuring stations often include this equipment.

Concerning the selection of which pollutants to study, please see 3.4.

4.1.2.2 Soil quality

Soil quality data may be obtained from the French National Institute of Agronomic Research, Chambers of Agriculture or the DREAL (Regional Environment, Development and Housing Departments).

Specific measurement campaigns sometimes have to be carried out by taking samples on the site and analysing them in the laboratory.

4.1.2.3 Inventory of emissions

General data on emissions related to road traffic can be obtained from inventories of emissions by source from the DREALs and CITEPA (Technical Interprofessional Centre for Atmospheric Pollution Studies).

In the majority of these cases, data can only be obtained at a sufficiently fine scale through modelling.

4.1.2.4 Meteorological, topographical, rugosity and buildings data

For useful sources of weather, topography, rugosity and buildings data please see 4.3.3.

4.1.2.5 Population data and health indicators

Under the *circular of 17 February 1998 [1]* a study of the health effects of projects is mandatory.

The initial status must identify the populations at risk in the study strip, specifying:

- their type (residential, offices, businesses, schools, etc.),
- their number (number of individuals or communities affected by emissions) for each effect category,
- their degree of exposure depending on their distance from the source or their activity,
- their relative sensitivity or vulnerability (hospitals, schools, etc.).

This data may be drawn up on the basis of INSEE "Îlots" or "Iris" databases (18), aerial photographs, town planning documents or field surveys.

In addition, the land use databases cited in 4.3.3 might also be useful for the population estimation work.

Particularly vulnerable sectors such as public spaces and facilities, residential areas and sensitive establishments such as hospitals, clinics, care homes or schools should also be located.

Health indicators concerning the populations listed can be obtained from the ARS (Regional Health Authorities), ORS (Regional Health Watchdogs) and the CIRE (Inter-regional Epidemiology Units).

(18) French National Institute of Statistics and Economic Studies

4.2 CALCULATION OF POLLUTANT EMISSIONS

4.2.1 Traffic data

The acquisition of traffic data is an essential preliminary stage for calculating pollutant emissions, as this is the data on which all subsequent calculations are based.

As the rest of this guide will set out, impact assessments during the preliminary studies are carried out with regard to annual average values. Emissions and concentrations in particular, should be assessed for an average hour of the year, and compared with annual concentration averages in the ambient air specified by the Law on Air.

For projects in interurban environments, the annual average traffic value to be taken into account will always be directly available, as in such cases, traffic studies are carried out for an average hour of the year. The values provided, which correspond to the traffic on an average day of the year broken down into passenger cars and heavy goods vehicles are expressed in "Annual Daily Average Traffic" (ADAT). These are the values to be used for the impact study.

For projects in urban areas, the annual average traffic value is not given directly by traffic studies, which for most of the time exclusively relate to episodes of network saturation. Consequently, the type of data supplied relates to the evening rush hour (ERH) or the morning rush hour (MRH), all types of vehicles being counted in passenger car units (pcu). For the purposes of the impact study on air quality it will therefore be necessary to change the traffic values at rush hour into annual average traffic values. This should be based on traffic measurements taken continually, which will enable a comparison to be made between the total daily traffic and rush hour traffic. This comparison varies according to the type of road (street, road, expressway or motorway), the environment in question (town centre, urban periphery, open countryside) and of course the level of saturation. When no particular data is available an approximate ratio is obtained by taking a value of 10: Rush hour traffic = annual daily average traffic / 10.

4.2.2 Emission factors

The quantity of pollutant coming out through the portals depends, firstly on the number of vehicles passing through the tunnel (road traffic) and, secondly, on the unitary emission of vehicles.

Pollutant emissions are calculated from unitary emission factors which correspond to the mass of pollutant emitted by a moving car. These emission factors are expressed in g/km/vehicle.

For more details on the parameters influencing emissions see the guide *"Road traffic related pollutant emissions and consumption: determinant parameters and method of quantification" [38]* published by ADEME. This guide deals with the question of choice of car fleet which is not dealt with here.

4.2.3 Calculation methods available

Four methods of calculating emissions may be cited here:

- Copert method,
- Tunnel Study Centre method,
- World Road Association method,
- ARTEMIS method.

4.2.3.1 Copert Method

The emission factors are given by the COPERT III (Computer Program to Calculate Emissions from Road Transport) and COPERT IV reports published by the European Environment Agency in July 1999 and August 2007. COPERT IV is an update of the emission factors proposed in COPERT III.

The factors depend on the type of vehicle (passenger car, light utility vehicle, heavy goods vehicle, coach, bus or two-wheeled vehicle), its fuelling system (petrol or diesel), its cylinder capacity and date of entry into service. These emission factors were determined through actual measurements carried out by several European laboratories over a large sample group of vehicles. France is represented by the French National Institute of Research into Transport and Safety (INRETS now IFSTTAR), which has worked for many years on understanding unit emissions.
The COPERT methodology enables the following to be taken into account:

- hot emissions,
- cold emissions for light vehicles,
- over-emissions linked to gradient for heavy goods vehicles, buses and coaches,
- over-emissions linked to the load of heavy goods vehicles, buses and coaches,
- corrections linked to fuel improvements,
- evaporation on stopping and while moving for petrol driven cars and two-wheeled vehicles.

Unitary emissions are quantified for precise kinematic cycles, which enable emission curves to be established in accordance with average speed.

4.2.3.2 Tunnel Study Centre (CETU) method

CETU has developed a road emissions calculation method specially adapted to the case of tunnels. This method is described in the document entitled *"Calculation of pollutant emissions from motor vehicles in tunnels" of April 2002 [39]*, available from CETU. This consists of multiplying unitary emission factors according to the type of vehicle, its technology and traffic conditions by the number of vehicles driving through the tunnel. Several parameters must be taken into account, such as the planning horizon, the type of route and the altitude.

The aim of the method is to take into account variations in heavy goods vehicle characteristics (mass, power and age) depending on the type of route (urban, inter-urban or international).

The data it uses comes from studies carried out as part of the various European programmes in which Germany, Austria, Belgium, France, Greece, the United Kingdom and Switzerland have taken part. It includes not only the COPERT III results but also the TUG (Austria) results provided by the Road Tunnel Operation Committee of the PIARC, and specific measurements made by INRETS at the request of CETU.

This method is in the process of being updated. The new version will include very recent data drawn from the COPERT IV database. Emission factors measured on the latest vehicles (Euro IV) will thus be taken into account, as well as emission factors for future vehicles, built from Euro V and Euro VI regulations. The updated method will moreover include the latest version of the French car fleet supplied by INRETS. This new method will be published by CETU in 2012.

4.2.3.3 World Road Association (PIARC) method

This method is set out in the PIARC guide *"Road Tunnels– Vehicle emissions and air requirements for ventilation of tunnels" [34]*. This method and the CETU method are very similar. The databases used for establishing unitary emission coefficients are partly shared by the two methods. The data source is mainly European (particularly Austria, Germany, Switzerland and the Netherlands) with the most recent data including that from the Artemis, Particulates and Cost 346 research programmes.

The main flaw of this method is that it does not include specific national car fleets. For a tunnel calculation in France it will not therefore be possible to take special French characteristics into account (diesel rate for example).

An updated version of the PIARC method will be published shortly.

4.2.3.4 ARTEMIS method

The Artemis model, published in October 2007, was developed at European level in the interests of standardising the calculation of pollutant emissions from roads. It includes a database of emissions from several European countries. Instead of proposing emission factors varying with the average speed of vehicles, Artemis proposes a traffic situation approach, defined by:

- area (rural or urban),
- traffic condition (fluid, saturated, etc.),
- type of road (motorway, trunk road, etc.)
- speed limit.

Work is in progress to produce a tool based on the Artemis methodology. The aim of the future "Impact-Artemis" tool (called Ademis), developed by Ademe, is simplified use of the Artemis method, notably reducing the number of traffic situations and adapting them to the needs of future users.

4.2.4 Choice of method

The purpose of this chapter is not to impose one method for the calculation of pollutant emissions. It is merely to say that in the case of road projects in general the COPERT methodology is the one most commonly used by design offices.

Where tunnels are concerned, the emissions data set out in the CETU guide *[39]* and the PIARC guide *[34]* are a bit more suitable, as they enable certain of their specific features to be taken into account (for example particulate matter and the calculation of opacity from particulate concentration values). It is therefore advisable to use these methods instead, and in particular the updated CETU method (due out in 2012).

4.3 CALCULATING POLLUTANT DISPERSION IN THE VICINITY OF TUNNELS

4.3.1 The issue

Air quality in the vicinity of road tunnels is an essential element to be factored into studies on these structures and their ventilation.

The particular nature of a tunnel portal is that it constitutes a discontinuity from the point of view of admissible and observed pollution levels. In terms of acceptable levels, higher pollution levels are tolerated in a tunnel than in the open air, as exposure times are shorter. Furthermore, even though it generates no more pollution than a road in the open, a tunnel is a confined space in which pollutants emitted by traffic accumulate, so that the portals constitute a source of concentrated pollutants in relation to the external environment. It is clear therefore that compliance with ambient air standards in the vicinity of tunnel portals is an issue that should be examined and that compliance with standards in the tunnel thanks to good ventilation management does not guarantee that there will not be an air quality problem at the tunnel portal.

The challenge of modelling the dispersion of pollutants discharged from a tunnel is to describe the concentration field within the impacted area outside the tunnel, where the pollution levels are certainly less than those in the tunnel, but may however exceed the threshold values specified by the Law on Air for health protection. The study of pollution dispersion is a major stage in the environmental impact assessment of a tunnel.

Pollutant behaviour and development modelling is based on four fundamental stages:

- precise definition of study specifications and choice of modelling tool,
- collection of input data: orography, land use, meteorology, emissions,
- computation of pollutant dispersion and possibly of pollutant conversions,
- use of the results.

4.3.2 Definition of the dispersion study and choice of model

While there has been a lot of research on the atmospheric dispersion of pollutants, it is still a complex issue and the case of tunnel portal discharge itself constitutes a particular problem to be dealt with. In contrast to most of the usual sources tunnel portals involve a certain horizontal momentum. Flow is very complex here and is the result of interaction of a jet with the planetary boundary layer. The accepted parameter for quantifying this interaction is the ratio between the speed of discharge and the wind speed at a reference altitude (generally 10 metres above ground level). To this special feature is added the usual phenomena of atmospheric dispersion: effect of traffic, thermal stability, consideration of the chemistry, etc.

Before choosing a model the desired level of precision must be defined. It is should also be borne in mind that the dispersion calculation is just one stage of the impact study, and its accuracy must be consistent with that of the other data sources (traffic study and meteorological study). Clearly defined study objectives are therefore essential.

Certain points merit careful identification in order to select which calculation tool to use:

- targeted pollutants: gas or particulate matter, primary pollutants presumed not to interact with other components of the atmosphere or secondary pollutants resulting from reactions;
- the nature of sources taken into account: ventilation stack, tunnel portal, etc.
- spatial scale: scope of the computational domain, which may vary by a few hundreds of meters around the source (local scale) to a few tens of kilometers (urban scale);
- level of detail of the site description (presence of obstacles or buildings, complexity of relief, assessment of any surface irregularities, etc.);
- time frame, for which two possible analyses may be schematically defined:
  - analysis of chronic pollution levels in order to assess the exposure of populations and the effects on their health. Health risk assessment scenarios are usually targeted on an annual, or even pluriannual basis. Input data (emissions and weather) are therefore considered over a long period of about a year. Emissions are average values possibly weighted according to the season or other parameters; meteorological data come from wind roses and stability wind roses;
  - analysis of the worst case scenario for one or more sources of pollutants (the calculation is carried out for a weather condition and fixed emissions data - this is a stable calculation, without change over time).

4.3.3 Inventory of input data

4.3.3.1 Weather

The choice of meteorological data depends directly on the time scale chosen for the calculations. For an analysis of chronic levels, the concentration levels must be calculated for each weather situation, then the "average" concentration calculated in proportion to the occurrence of each situation on the wind rose is deduced. For the study of the worst case scenario only the corresponding weather condition is necessary.

All the data (wind roses, thermometry and height of the mixing layer) may be obtained from the nearest Météo France station to the project site. The extent to which this data can be used must always be taken into consideration as local conditions at the site may be very different from those of the Météo France station.

4.3.3.2 Rugosity and topography

The characteristics of the ground have a very great influence on flow and dispersion. They are taken into account on the whole by the height of ground irregularities z_o (expressed in metres), which depends on relief, the size and distribution of any buildings present and the nature of the ground (sea, woodland, grassland, built-up, etc.).

At national level, the Corine Land Cover and BD Carto® files, describing land use may be used for determining rugosity in the study area. ISBA (Soil-Biosphere-Atmosphere Interactions) digital representation diagrams of energy transfers between the soil, vegetation and the atmosphere developed by the French National Centre for Meteorological Research (CNRM, joint CNRS-Météo-France research unit) may also be used.
The main database for finding out about the topography of the site is BD Alti® from the French National Geographical Institute (IGN), which is an extract of the BD topo®.

4.3.4 The different types of model available

The choice of pollutant dispersion model, which depends on the answers to the previous questions is made from a very varied range of tools.

From the simplest to the most complicated, depending on the context, the following models may be used: empirical approach, box models, simple gaussian models, lagrangian models, eulerian models and physical modelling.

4.3.4.1 Use of measurements taken on site or on a mock-up

Various empirical models of tunnel portal discharge have been produced from measurements taken in situ or on mock-ups (Norwegian Road Administration for example *[40]*). They may constitute an initial approach, but it should not be forgotten that the result they produce is only an approximation.

It may also be useful to consult the CETU case catalogue *[41]*, which is a compilation of the most interesting results from physical modelling (hydraulic and aeraulic mock-ups) commissioned by CETU up to 1998. For ten or so different configurations of tunnel portal outlets, the catalogue gives, in a fixed format, the following elements:

- a photograph of the mock-up made and tested,
- the characteristics of the structure and the experimental conditions of the study,
- a plan view of the mock-up showing the buildings, site of pollutant concentration measurement points and the wind directions studied,
- a diagram of the results specific to each pollutant concentration measurement point according to the wind direction and its relative intensity.

4.3.4.2 Multiple box models

In multiple box models *[42]*, the study field is cut into several boxes distributed throughout its volume. The concentrations are presumed uniform within each volume, and by carrying out assessments on these boxes a concentration field is obtained for the whole area. The velocity field should also be calculated, and the end result obviously depends greatly on the previous calculation.

4.3.4.3 Gaussian models

Gaussian models were initially developed to represent the behaviour of a plume from a stack. They are based on the analytical solution of the advection - diffusion equation. Under certain scenarios (uniform wind field, closure by a turbulent Fick's law), a simple description of the concentrations field is obtained.

This formulation introduces dispersion coefficients in horizontal and vertical directions perpendicular to the direction of flow, and one of the main difficulties of implementing these models lies precisely in obtaining a correct value for these coefficients. They are usually given as a function of the distance from the source, wind strength and atmospheric stability. In order to formalise the basic notion of "atmospheric stability" a classification based on observations of the vertical thermal gradient, nebulosity or even solar radiation and other meteorological parameters was established (Pasquill, Gifford, and Turner atmospheric stability classes).

The simplicity of the analytical approach of gaussian models makes them suitable for calculations over the long term. In fact it is entirely possible to carry out thousands of calculations corresponding to all time situations over a year in order to extract an annual average concentration. However, their validity field is restricted, making them tricky to use, as:

- the description of the concentration field is imprecise near the source;
- their use remains limited to situations in which the relief is small and there are no obstacles;
- low winds (less than 0.5 m/s) cannot be dealt with properly, as the plume then no longer has a gaussian profile (but this poor ability to deal with low winds is common to nearly all the models).

4.3.4.4 Sophisticated gaussian models

From gaussian models in the strict sense of the term, a new generation of more sophisticated gaussian models has been developed to take account of relief, the presence of buildings, a more complex velocity field, chemical reactions, etc. The computation of dispersion coefficients has also been refined, resulting in a continuous parametrisation according to the characteristics of the planetary boundary layer.

Even with these improvements, computation times for gaussian models are still short, just a few minutes for a given weather situation, which means complete wind roses can easily be calculated.

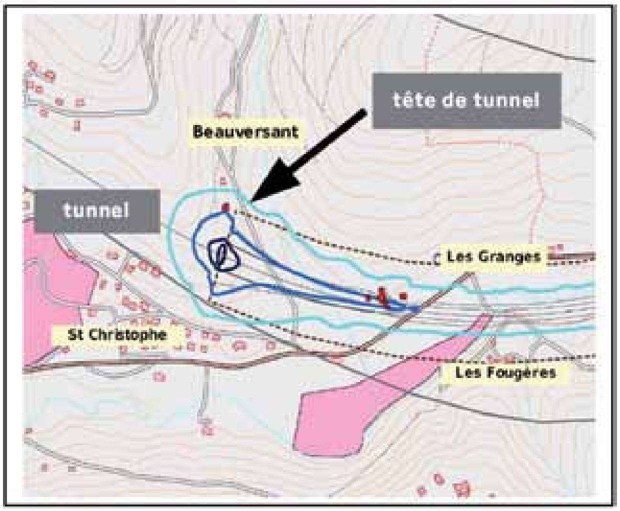


Illustration 12 - Map of concentrations of nitrogen dioxide calculated with the aid of the ADMS software ("sophisticated" Gaussian model) - CETE de Lyon

4.3.4.5 Lagrangian models

In lagrangian models, plumes are described by the movement of their components, which are monitored as they move. This category includes gaussian puff models and particulate matter models.

In gaussian puff models, which are used for non stationary and non homogeneous emissions, the discharge is considered as a succession of puffs which develop in a gaussian way.

In particulate matter models, several thousand particles are "released" and their trajectory calculated, then the concentration is deduced by statistical treatment of these trajectories.

The lagrangian approach is effective in near-field but quickly becomes cumbersome if the number of sources is large.

4.3.4.6 Eulerian models

Models based on the digital solution of basic fluid mechanics equations (Navier-Stokes equations) for the dynamic part, and the advection-diffusion equation for the dispersion of pollutants, are also called "eulerian" or "3D" models. In these models the equations are separated in time and space, which means a grid has to be placed over the study area, and the construction of this grid determines the quality of results and the calculation time. A judicious grid strategy consists of using a fine grid in areas where physical phenomena are decisive factors (near the ground, close to obstacles) and larger meshes in the less problematic areas.

Such models enable complex flows to be dealt with and specific effects taken into account such as chemistry for example. They are however heavy and costly to implement, and the user has to make many careful choices (mesh size, turbulence modelling, definition of conditions at the edges of the field, etc.), which require sound skills. Information on the proper use of these models is given in Appendix D of part 4 of the *Guide to Road Tunnel Safety Documentation [12]*.

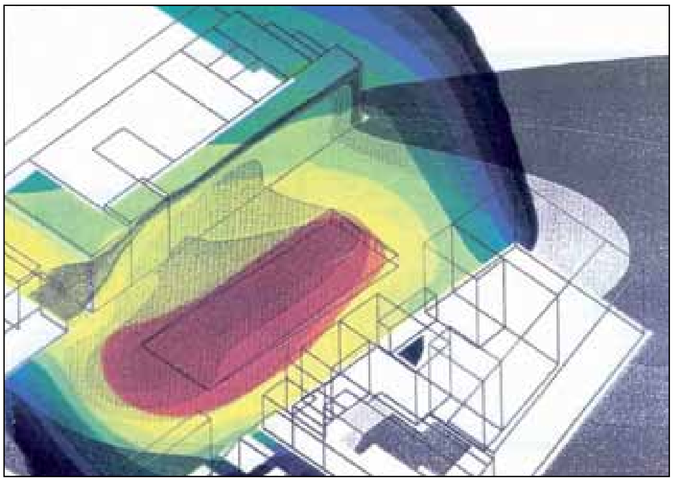


Illustration 13 - Presentation of results of 3D digital simulation - Field of concentration (ARIA document)

In models based on the separation of Navier-Stokes equations and the advection-diffusion equation, the computation time needed to model a given meteorological condition is several hours, which makes it almost impossible to model a complete wind rose.

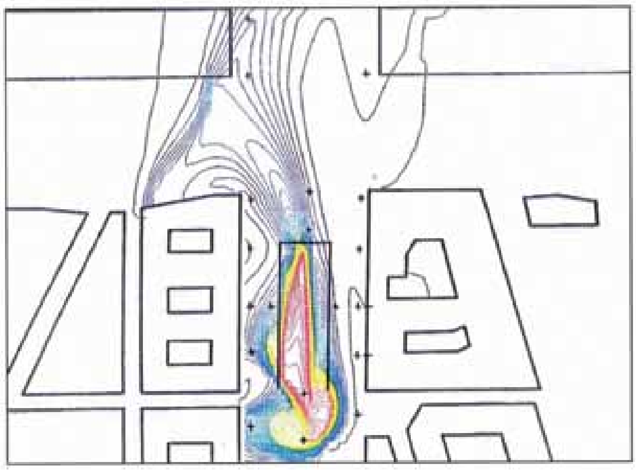


Illustration 14 - Presentation of 3D digital simulation results - Concentration curves (INERIS document)

4.3.4.7 Physical models

Physical modelling consists of reproducing the site on a small scale mock-up, in a hydraulic or aeraulic working section. It is based on the notion of similarity and enables very complex sites to be studied.

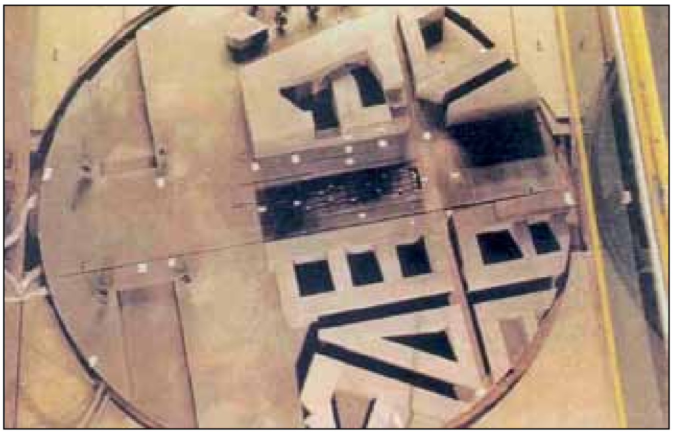


Illustration 15 - View of a hydraulic mock-up installed in a working section (CERG document)

For more information on the principle of mock-ups please see the Guide for factoring in air quality in the vicinity of road tunnels *[32]*, published in June 2000 by CETU.

Illustration 16 - View of an aeraulic mock-up in a wind tunnel (CSTB document)

type of model	standard gaussian	sophisticated gaussian	lagrangian	eulerian	physical
advantages	• easy to implement • simple statistical analysis • rapid computation times	• simple to implement • simple statistical analysis • option of factoring in relief and some obstacles in near field • possibility of taking chemistry into account • moderate computation times	• fairly rapid computation times	• option of processing complex flows • possibility of taking chemistry into account	• option of processing complex flows • reliable results
disadvantages	• not suitable for near field • very simplified approach • not suitable for small-scale complex sites • chemistry not taken into account	• limitations in near field • simplified approach • problems in cases of complex topography (such as cliffs)	• chemistry can be taken into account but complex	• difficult to implement • tricky to use	• difficult to implement • chemistry not taken into account
cost	low	low	average	high	very high
scope	global studies	recommended for studies leading up to the declaration of public utility	little used at present for tunnel portals	reserved for cases where the architecture and the positioning of tunnel portals are precisely known	reserved for very detailed studies

Table 4 - Summary of the characteristics of modelling tools

4.3.4.8 Summary

The different approaches presented are compared in table 4.

It seems that depending on the characteristics of the study to be carried out some approaches are not appropriate.

Standard gaussian models are very simple and will be reserved for comprehensive large-scale studies.

Sophisticated gaussian models, capable of considering such phenomena as chemistry or relief and using a refined calculation of the dispersion coefficients, will be very suitable for the stages preceding the declaration of public utility. But they will not be suitable for a precise study on a complex site as they may not take proper account of buildings.

In this case physical modelling is a better approach in spite of the cost. The use of models based on the separation of the Navier-Stokes equation and the advection-diffusion equation, which requires significant investment, is also reserved for the study of particularly sensitive sites from the point of view of air quality.

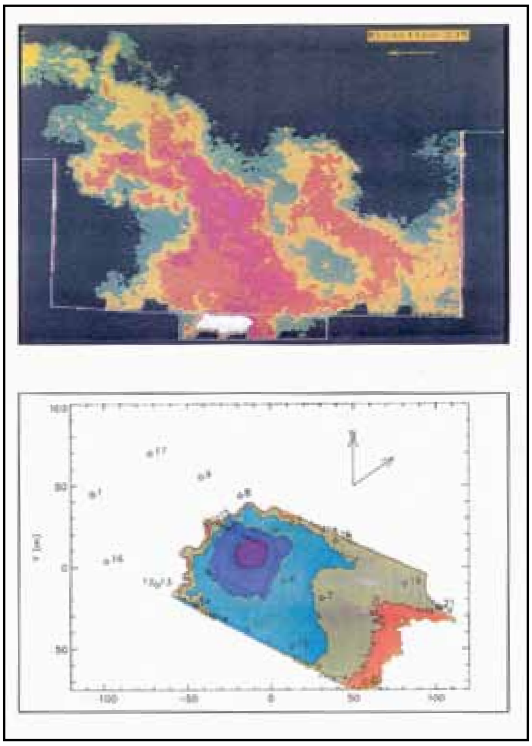


Illustration 17 - Physical models - Examples of flow visualisation and concentration distribution obtained by laser image processing-induced fluorescence (CNRM document)

4.4 CONTENT OF THE HEALTH SECTION

Once the exposure levels have been calculated, the health section of the tunnel impact study is not treated any differently from open road projects. To make things easier for the reader, the following paragraphs briefly recap the study method. Useful references for further reading are also given.

4.4.1 Reminder of the legal framework and the context

Under article 19 of the *Law on Air [5]*, a study of the project's impacts on health should be drawn up for all projects requiring an impact study. This study should be accompanied by measures intended to remove, reduce and if possible compensate for the adverse effects of the project on the environment.

The Minister for the Environment's *circular of 17 February 1998 [1]*, specifies the general principles for drafting the health section of impact studies. These various points are as follows:

- the study should cover all relevant issues concerning health risks presented by the project (air, noise, water, soil and road safety) and assess the direct and indirect impacts;
- the study should assess the cumulative effects in relation to external nuisances;
- the study should quantify the size of population at risk;
- the study of impacts on health relates both to the works phase and the operational phase.

In the *circular of 3 February 2000, the Minister of Health sent the decentralised departments* a guide *entitled "Guide to reading and analysing the health section of impact studies" [7].* This guide recommends following the risk assessment procedure formalised in the United States by the National Academy of Sciences, the Federal Food and Drug Administration and the Environmental Protection Agency. This procedure has been used in France in the context of the national policy for management of polluted sites and soils (Ministry of the Environment, 1999).

In a *circular of 11 April 2001 [8]*, the Ministry of Health recommended that prefects should rely on the Regional Health Authorities for analysing the content of studies on the impacts on health in relation to projects subject to impact studies. The appendix to the circular gives the minimum content of these studies.

The Health - Public Works - Ecology Circular of 25 February 2005 states and clarifies the methodology to be used for taking account of the effects of air pollution on health in impact studies on road infrastructure.

Another important circular in terms of the risk acceptability threshold is the *circular of 10 December 1999 [43]* issued by the Ministry of the Environment on the objectives of soil cleanup. In fact this is the only document in France that specifies an individual risk threshold not to be exceeded for pollutants without a threshold. This threshold (19) is 10^{-5}.

4.4.2 Technical documents

The main technical documents which state the procedure in France are the following:

- INERIS frame of reference: *"Assessment of Health Risks in Impact Studies on Listed Installations for Protection of the Environment - Chemical Substances" [44]* published in 2003, intended for industrial cases,
- the Institute of Health Monitoring's guide: *"Guide to the analysis of the health section of impact studies" [45]* of January 2000,
- the working report *"Selection of dangerous agents to be taken into account in the assessment of health risks linked to road infrastructure" [46]* of November 2004,
- the *methodological note on the assessment of the effects of air pollution on health in road impact studies (CETU and SETRA) of February 2005 [3]* which specifies the necessary components of this approach.

Other documents also give information on the effects of atmospheric pollution on health. The publication of the French Society of Public Health on *"Atmospheric pollution from cars and public health" [47]* which takes stock of 15 years of international research.

The report entitled *"Selection of dangerous agents to be taken into account in the assessment of health risks linked to road infrastructure" [31]* was drawn up by a working group consisting of members of the French General Directorate for Health, ADEME, InVS, INRETS, CERTU, SETRA and CETE Méditerranée. It is intended for decentralised departments and research departments.

Its objective is to propose a list of the various substances to be taken into account in health risk assessments conducted in the context of road projects, as well as the health impacts to be considered and the most relevant human health toxicity values to be used for the proposed substances.

This corresponds to the initial stages of the work to be carried out in any health risk assessment.

The end purpose is to help the professionals in research departments to conduct the most appropriate studies in terms of relevance and feasibility, and to facilitate the work of government departments responsible for analysing impact studies.

4.4.3 Content of the health section according to the study level

The content of the health section depends on the level of study required (cf. 4 - Assessment tools, from initial status to health risk) :

- level I studies require a detailed "health" study with comparison with statutory air quality thresholds;
- level II studies require a simplified analysis of impacts on health using the PPI (population - pollution exposure indicator - cf. 6.1.3);
- level III and IV studies require basic information on the impacts of atmospheric pollution on health.

4.4.3.1 Level I study

For this level of study a detailed health study must be carried out. The approach selected should follow the methodology recommended by the InVS guide *[25]*, as presented in the General Directorate of Health circular of 11 April 2001 on the analysis of effects on health in impact studies, and the reading grid in the InVS guide which promotes the health risks assessment approach (ERS) *[24]*.

The health risks assessment approach has four stages.

Stage 1: Identification of the risks

This first stage consists of listing the dangerous agents that could be emitted by the infrastructure and then identifying the toxic effects of each dangerous agent, by respiratory tract and oral route, depending on the period of exposure. A reasoned choice of risk tracer elements is carried out depending on the intrinsic toxicity of each element.

(19) this value of 10^{-5} corresponds to the probability of seeing one cancer appear in every 100,000 individus, due to exposure to a carcinogenic agent.

Stage 2: Characterisation of dose-response or dose-effect ratios

This stage concerns firstly describing the symptoms that could be observed following short exposure and long term exposure, and secondly the choice of human health toxicity values (HHTV). Although these values are not given in the rules they do appear in the scientific literature. Two types of effect can be distinguished: systematic or threshold effects and effects without threshold, or carcinogenic or genotoxic effects, for which different HHTVs are available (see inset). HHTVs (numerical values established by national or international authorities from a detailed examination of toxicological and epidemiological knowledge) describe the ratio between a dose and a danger.

Toxic effects with or without threshold

The final stage of the health risk assessment has two parts: calculation of the risk estimates and analysis of uncertainty, part of which is similar to the discussion which goes on around any scientific study. Risks to human health are estimated differently depending on whether or not the risk is considered to arise above a dose limit.

Two types of toxic effect are usually distiguished:

- threshold level toxic effects,
- nonthreshold toxic effects,

Threshold level toxic effects

Where acute and chronic non carcinogenic effects are concerned a risk quotient (RQ) is calculated by taking the ratio between the average daily intake (ADI), or the average concentration in the air (AC) for the respiratory tract, and the human health toxicity value, for the route of exposure under consideration. This value is not a risk and the assessment here is qualitative in nature: a ratio of less than 1 means that the exposed population is theoretically out of danger, while a quotient above 1 means that the toxic effect could manifest itself, without it being possible to predict the probability of this event occurring.

Nonthreshold toxic effects

For carcinogenic and mutagenic effects the risk assessment is really quantitative. The probability of cancer occurring in the lifetime of the subjects exposed which is added to the basic risk not linked to this exposure is called excess lifetime cancer risk (ELCR): it is calculated for each route by multiplying the excess unitary risk (EUR) by the average daily total "lifetime" (or relevant unit of time) dose or by the "lifetime" concentration in the air.

This risk multiplied by the number of people exposed gives the excess collective risk (ECR), also known as the impact. It represents an estimation of the number of excess cancers linked to a studied exposure which might occur in the course of the life of this group of individuals.

These HHTVs thus enable the relationships between a dose and a dangerous agent and the frequency (response) or severity of the danger (effect) caused by it to be established.

For carcinogenic effects the EUR (Excess Unitary Risk) will be given, which is the slope associating the probability of effects at the toxic dose for low values of the dose. This is a linear hypothesis enabling the probability beyond the domain of the dose actually experienced to be calculated. This is a high estimation of the risk of a cancer appearing per unit dose linked to an exposure during the lifetime applicable to all individuals of a population, whether or not they belong to a sensitive group.

For non carcinogenic effects the maximum allowable concentration in the air (MAC) is given when exposure takes place through the respiratory tract. The MAC defines the theoretical maximum content of a toxic agent in the ambient air, for a specified exposure time, that an individual, whether from a sensitive group or not, can inhale daily without any adverse effects on his or her health.

Stage 3: Assessment of exposure

Assessment of exposure consists, firstly, of describing the people exposed (age, sex, physiological characteristics, any pathologies and sensitivity) and the routes by which the toxic agents enter the body. Secondly, it should quantify the frequency, duration and intensity of exposure to these substances – expressed as average daily intake or, for inhalation, by an average concentration in the air for each relevant route.

Stage 4: Characterisation of health risks

The final stage of the health risk assessment has two parts: risk assessments and uncertainty analysis. This stage consists of summarising and connecting the information gathered in previous stages, as well as carrying out a critical analysis of the validity and potential extent of the risks.

4.4.3.2 Level II study

This simplified study of the comparison of options and the accepted solution in relation to health is carried out by using a simplified health indicator (population - pollution exposure indicator (PPI) - cf. 6.1.3) comparing the benzene emission or concentration data and the population data. In addition to the PPI in benzene, a calculation for nitrogen oxides is recommended, as these are more sensitive to variations caused by the various development scenarios under consideration.

4.4.3.3 Level III and IV studies

For this level of studies the health section is very simple as it includes little more than basic information on the effects of atmospheric pollution on health.

4.4.4 Pollutants to be selected according to the study level

For a level I study the following pollutants are used for assessing the health risk:

- standard pollutants: sulphur dioxide, carbon monoxide, nitrogen dioxide, particles from vehicle exhaust,
- volatile organic compounds: benzene, 1.3-butadiene, acetaldehyde, formaldehyde, acrolein,
- polycyclic aromatic hydrocarbons: benzo(a)pyrene,
- metals: arsenic, barium, cadmium, chromium, mercury, nickel, lead.

For level II, III and IV studies, the pollutants to be taken into account are those cited in the *methodological note [3]*, namely:

- nitrogen oxides (nitrogen monoxide and nitrogen dioxide),
- carbon monoxide,
- hydrocarbons,
- benzene,
- particles emitted with exhaust,
- sulphur dioxide,
- nickel,
- cadmium.

5. THE CONTENT OF FEASIBILITY STUDIES

At the feasibility study stage the subject of air quality and tunnels should above all be tackled through a presentation of the project and an outline of the phenomena at stake. To understand this approach properly readers who are not tunnel specialists should refer to chapter one of this guide, which gives general information.

Sometimes, especially if homes are in the immediate vicinity of the project, expectations are greater and general information is not sufficient. A very simple study can then be planned with the aim of characterising the tunnel's sensitivity.

A method for establishing the project's level of sensitivity is proposed in this chapter. It does not aim to assess the absolute impact of the tunnel.

In the light of the level of uncertainty linked to the many simplistic hypotheses used, the results should be interpreted and analysed with the utmost caution.

In order for it to be used from a very early stage in the studies the method proposed in the following paragraphs is very simple.

It can be applied in the same way regardless of the level of study as defined by the *methodological note [3]*, from the fullest, level I to the smallest, the level IV.

It can also be used, as an initial approach, during the later study stages. It is then a matter of detecting whether the project may raise problems from the point of view of air quality, in which case the most sophisticated methods described in chapters 6 and 7 can be implemented later.

The successive stages of the method are described below, then summarised in a logical diagram.

5.1 ESTIMATION OF CONCENTRATIONS AT THE PORTALS

5.1.1 Calculation of pollutant emissions

Pollution emissions are calculated according to the methodology recommended in 4.2, for nitrogen oxides, particulate matter and benzene.

The traffic figures are those of an average hour of the year, at the planning horizon accepted for the other environmental studies (annual average hourly traffic - cf. 4.2.1).

The annual average hourly traffic is obtained from the annual daily average traffic which is almost always available at this stage of studies.

5.1.2 Distribution of emissions between the two portals

In general, emissions in one tunnel portal can be taken to be equal to half the emissions calculated over the covered part of the route (cf. 1.6.3). This is particularly true in the case of two one-way tubes side by side, or in the case of a two-way tube.

One exception is of course the case of a single one-way tube, where all the emissions are discharged at the vehicle exit portal.

5.2 ROUGH ASSESSMENT OF DISCHARGE CHARACTERISTICS

5.2.1 Discharge velocity

In the absence of computation, it can be assumed that the velocity of air leaving the tunnel is 3 m/s, which is the minimum velocity that longitudinal systems should be capable of providing in relation to fire safety. In general, the piston effect of vehicles leads to markedly higher flow velocities. The assumption is more concerned with safety than the risk of pollution.

The flow of air leaving the tunnel is therefore Q = 3 x S, S being the section of the tunnel (Q in m^3/s and S in m^2).

5.2.2 Discharge concentration

The discharge concentration C_0 at the tunnel portal for a given pollutant is C_0 = Emission / Q (the emission being expressed in units of mass per second).

If these calculation hypotheses result in a concentration C_0 greater than the recommended concentration in tunnels, this means that the piston effect is insufficient to provide fresh air ventilation, and that in practice, mechanical ventilation should be implemented. It can then be assumed that the discharge concentration C_0 is equal to the recommended threshold (cf. 3.3), which constitutes an unfavourable hypothesis.

Nitrogen oxides are dealt with in a special way. As emissions are known for total nitrogen oxides, while regulatory thresholds are laid down for nitrogen dioxide only, the discharge concentration in nitrogen dioxide is estimated by assuming that in a tunnel the NO_2/NOx ratio is equal to 0.1 or at a higher value (cf. 3.6).

5.3 TAKING DILUTION INTO ACCOUNT

The pollutants emitted by the discharge from the tunnel contribute towards creating an over-concentration in relation to the level that would be achieved in the absence of the tunnel. This over-concentration decreases rapidly however with increasing distance from the tunnel portal.

Many modelling studies on mock-ups have been carried out at CETU in the past. They essentially cover the meteorological conditions (wind direction, wind strength and atmospheric stability conditions) and the many geometrical configurations of tunnel portals.

All these results have been compiled in the *Catalogue of cases [41]*. This document constitutes a rich source of information that will enable the project designer to understand the phenomenon of decreasing discharge concentration emitted from tunnel portals.

Use of the *Catalogue of cases* is not however recommended for estimating the concentration levels of a given project. In fact each project is too specific for the results obtained for another configuration, even similar in appearance, to be applied to it. Furthermore, the huge difference in the way modelling is carried out makes it impossible to calculate an average level of concentration computed across all the tests in the *Catalogue of cases*.

5.3.1 Proposed method

To offer the project designer a practical method the following concentration decrease values are recommended to be used, as an approximation, at the feasibility study stage. These are results obtained during 2003 and 2004, by measurements on aeraulic mock-ups. These measurements were made in the wind tunnel at the École Centrale de Lyon during thesis work financed by CETU. A detailed description of the tests and full presentation of the results are given in the test report *"Study on a mock-up of a dispersion scenario at a tunnel portal" [36]* cited above (cf. 3.6 -Nitrogen oxides).

The measurements were made for a very simple configuration: tunnel (or cut-and-cover tunnel) opening into a cutting (see figure below).

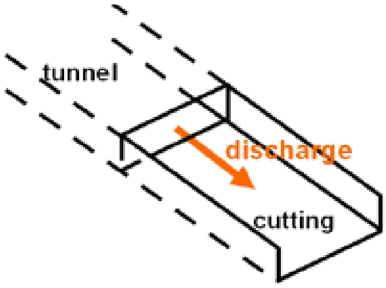


Illustration 18 - Geometry of the tested configuration: tunnel (or cut-and-cover tunnel) opening into an open cutting

The tests related to four velocity ratios (discharge velocity over wind velocity) and seven wind directions (from 0 to 180°).

From this data, a statistical study was carried out to establish the average concentration level at a point situated in the vicinity of the discharge, depending on its position in relation to the tunnel portal [20]. This position is defined by the angle θ and the distance d, θ giving the direction of the point in relation to the direction of the discharge, and d being the distance between the point and the tunnel portal (see illustration 19).

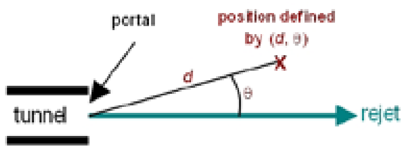


Illustration 19 - Definition of distance d and angle θ

The average concentration level was calculated by taking the same occurrence for each of the four discharge velocity / wind velocity ratios, at each wind direction. The values are given at 3 metres above ground level.

5.3.2 Cases of passive pollutants (benzene, particulate matter)

In the case of passive pollutants, the results of measurements taken on a mock-up are directly applicable : the dilution coefficient measured in the experiment is applied to the initial discharge concentration in order to assess the over-concentration caused by the tunnel at a given point. The total pollution level is then obtained by adding the over-concentration to the initial background level.

The shape of the concentration field obtained by experiment is shown in illustration 20.

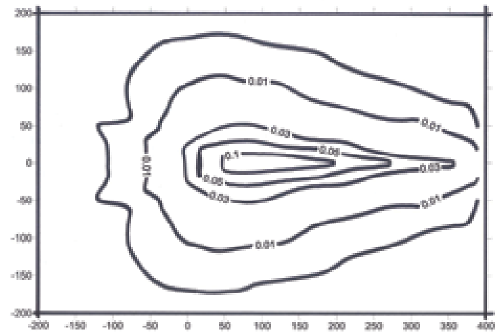


Illustration 20 - Concentration field obtained on average for all situations tested (relative concentrations C/C_0, distances in metres, on the two axes, in relation to the tunnel portal)

The numerical values of the concentration field obtained are given in table 5.

The size given is that of dilution coefficient $\alpha_{d,\theta}$. This is the ratio between the over-concentration $C_{d,\theta}$ caused by the tunnel at the point located by (d, θ) and the initial over-concentration of the discharge C_0: $\alpha_{d,\theta} = C_{d,\theta} / C_0$.

For example, at a point situated at a distance of 25 metres from the tunnel portal in a direction of 30° in relation to the tunnel axis, the dilution coefficient is 0.06, which means that the over-concentration at this point is 6, for an initial over-concentration at the immediate tunnel exit of 100. If the discharge concentration is 0.15 ppb of benzene, an over-concentration of 0.15 x 0.06 = 0.009 ppb of benzene is obtained at a distance of 25 metres from the tunnel portal, in a direction of 30°.

$\alpha_{d,\theta}$	distance *d* from the tunnel portal					
angle θ	25 m	50 m	100 m	150 m	200 m	300 m
0°	0,07	0,10	0,19	0,10	0,05	0,02
30°	0,06	0,05	0,03	0,02	0,01	< 0,01
60°	0,04	0,03	0,02	0,01	< 0,01	< 0,01
90°	0,03	0,02	0,01	< 0,01	< 0,01	< 0,01
120°	0,03	0,02	0,02	< 0,01	< 0,01	< 0,01
150°	0,02	0,01	< 0,01	< 0,01	< 0,01	< 0,01
180°	0,02	0,01	< 0,01	< 0,01	< 0,01	< 0,01

Table 5 - Tunnel discharge dilution coefficient for passive pollutants

(20) Although concentration measurements on a mock-up were carried out at points distributed on a regular grid it is apparent that the fact of only having localised values could strongly bias the statistical analysis. For this reason, before a statistical study is carried out a simple modelling of the field observed was carried out in order to transfer the localised measurements onto a continuous field.

5.4 SPECIAL CASE OF NITROGEN OXIDES

To estimate over-concentration in nitrogen dioxide due to the tunnel, the experimental dilution coefficient cannot be applied directly to the quantity of nitrogen dioxide present in the discharge. The quantity of nitrogen dioxide created by the reaction of nitrogen monoxide in the initial discharge should also be taken into account (see 3.6).

These reactions are very dependent on the surrounding conditions. This is manifested by a more or less rapid change in the NO_2/NOx ratio depending on the quantity of ozone present, radiation, temperature, etc.

In this case it is recommended that the results of the simplified model presented in 3.6 are used. A direct calculation of over-concentration in NO_2 due to the discharge is not possible: the total concentration in nitrogen oxides must be calculated first (over-concentration due to the discharge + background) by passive dilution (similar method to benzene and particulate matter), then the NO_2/NOx ratio from the simplified model (tables 16 and 17) applied to the result in order to obtain the concentration in NO_2. This approach is set out in the worked example given in *chapter 6*.

The NO_2/NOx ratio values are given for two scenarios (cf. 3.6):

- large urban area with high levels of background pollution in nitrogen oxides,
- medium-sized town with low levels of nitrogen oxide pollution.

These two scenarios do not cover all possible situations but they are sufficiently different to show how the variation in the NO_2/NOx ratio behaves according to the degree of urbanisation of the area in question.

The reader of this guide may choose the scenario closest to situation in hand, or reason within a range in the case of an intermediate situation.

5.5 CONCLUSION ON THE SENSITIVITY OF THE PROJECT

How sensitive the tunnel may or may not be is assessed by examining the level of background pollution, estimated over-concentration $C_{d,\theta}$ and the threshold specified as the regulatory quality objective.

The very simple method given here does not in any way claim to reflect particular situations in terms of weather or traffic conditions. For this reason it is the traffic over an average hour of the year and an average dilution rate resulting from a large number of weather conditions that is used.

The method consists of considering an average situation, which corresponds well to the health concerns for which the exposure of people living near the project has to be assessed.

Consistent with this approach, the regulatory thresholds to be used here are therefore the quality objectives relating to an annual average. These are laid down by the *French decree of 15 February 2002 [1]* for nitrogen dioxide, particulate matter and benzene (cf. 3.2.1).

It should be noted that $C_{d,\theta}$ is only an estimate aimed at assessing the sensitivity of the tunnel on its site, and does not allow the possible absolute impact of the tunnel to be assessed, due to the fact that high levels of uncertainty hang over the tunnel project at this stage.

If the total concentration, sum of the over-concentration $C_{d,\theta}$ due to the tunnel obtained in the previous paragraph and the background pollution, is less than the threshold laid down as the quality objective the tunnel is not sensitive.

If the total concentration is above the threshold laid down as the quality objective the project may be considered sensitive. In this case, the relative proportion of over-concentration due to the tunnel, over-concentration due to the part of the road in the open air, and the background pollution in the total concentration should be compared first, so the tunnel's effect can be put in perspective if the initial background level is already very close to the regulatory threshold, or even above it on some very urban sites. Moreover, it should be noted that the very simple method used is based on unfavourable assumptions, which overestimate the impact of the tunnel. At the feasibility study stage it is generally illusory to want more detailed calculations ; this in fact requires refining the characteristics of the project and the site data first, as well as factors that will be revealed at later study stages.

Feasibility studies - logical diagram of the proposed method

calculation of tunnel emissions E_{total}(g/h)
for NOx, PM, C_6H_6

distribution of emissions between the 2 portals
general case: $E_{portal} = E_{total} / 2$ (g/h)

S being the tunnel section (m²),
supposing Q = 3S (m³/s)
(fire safety requires
$Q_{FA(dimensioning)} \geq 3S$)

conversion of nitrogen oxides to nitrogen dioxide using NO_2/NOx = 0.1
(or a value greater than 0.1 - cf. 3.6)

calculation of the discharge concentration in NO_2, PM and C_6H_6
C_0 (µg/m³) = E_{portal} / Q x 10^6 / 3600

if $C_0 < C_{\text{regulatory in tunnels}}$,
C_0 is kept as over-concentration
at the tunnel portal

if $C_0 > C_{\text{regulatory in tunnels}}$, take
$C_0 = C_{\text{regulatory in tunnels}}$ as
over-concentration at the tunnel portal

over-concentration at the tunnel portal:
C_0 (µg/m³) for NO_2, PM and C_6H_6
and $C_{0\,[NOx]} = 10 \times C_{0\,[NO2]}$ (µg/m³) is calculated
(the factor 10 should be adjusted if NO_2/NOx = 0.1 not accepted)

assessment of the distance d between the tunnel portal and the nearest house estimation of the angle θ between the direction of the house and the direction of the discharge

choice of dilution rate $\alpha_{d,\theta}$

average over-concentration likely to be reached at the nearest house:
$C_{d,\theta} = \alpha_{d,\theta} \times C_0$ for NOx, PM and C_6H_6

assessment of the concentration of
background $C_{background}$ for NOx, PM and C_6H_6

choice of the NO_2 / NOx ratio depending on
d, θ and the environment in question

calculation of the total concentration at the nearest house
$C_{total} = C_{background} + C_{d,\theta}$ for PM and C_6H_6
$C_{total\,[NO2]} = (C_{background[NOx]} + C_{d,\theta\,[NOx]}) \times (NO_2 / NOx)$ for NO_2

Let's take a tunnel with a single 1500 metre-long two-way tube planned to cross a mountain range.

In view of the expected traffic upon completion of 14,000 vehicles per day with 10 % of heavy goods vehicles by 2015, it is planned to build a single two-way tube.

Although the site seems *on the face of it* without issues from the point of view of air quality, in view of the low level of background pollution and relatively small traffic volume, the presence of a hamlet with a few houses 60 metres from one of the portals leads to a study being carried out on the sensitivity of the project after the feasibility studies.

The study that might be carried out in this case is presented below, according to the methodology set out above.

5.1.1 Calculation of pollutant emissions

Inside the tunnel, for the two traffic directions, the average emissions calculated according to the Copert methodology are as follows (*table 6*):

pollutant	nitrogen oxides	particulate matter	benzene
total emissions (g/day)	11 536	296	8.2
total emissions (g/day)	481	12.3	0.34

Table 6

5.6.2 Distribution of emissions between the two portals

It is planned to ventilate the tunnel by a transverse system, operating only semi-transversally (injections of fresh air without extraction of polluted air) for health purposes. The discharge is therefore only at the portals and it can be considered that on average over a fairly long period the emissions are distributed equally between the two sides.

The emissions at one portal are therefore as follows (*table 7*):

pollutant	nitrogen oxides	particulate matter	benzene
emissions at a portal (g/h)	240	6.2	0.17

Table 7

5.6.3 Rough estimate of the discharge characteristics

As the tunnel section is 56 m², supposing a minimum velocity of 3 m/s, we obtain a flow of fresh air in the tunnel Q = 56 x 3 = 168 m³/s. From this we deduce the discharge concentration C_0 = (Emission / Q) x (10^6 / 3600) for the nitrogen oxides, particulate matter and benzene. We deduce the discharge concentration in nitrogen dioxide from that in nitrogen oxides, using NO_2/NOx = 0.3 (*table 8*). This value of 0.3 corresponds to a ratio now commonly encountered in tunnels.

pollutant	nitrogen oxides	nitrogen dioxide	particulate matter	benzene
discharge concentration (µg/m³)	397	119	10	0,3

Table 8

The recommended thresholds in tunnels, expressed in µg/m³ (cf. table 2), are as follows [21] (*table 9*):

pollutant	nitrogen dioxide	particulate matter
recommended threshold in tunnels (µg/m³)	752	500

Table 9

For the two pollutants, it is noted that the discharge concentration is lower than the recommended threshold, the value calculated as over-concentration due to the tunnel at its portals is therefore accepted.

5.6.4 Taking dilution into account

As the house nearest to the portal is situated in a direction of 60° from the tunnel axis and a distance of 60 metres, a dilution coefficient of α = 0.03 is accepted.

This coefficient is applied directly to the discharge over-concentrations, which gives the over-concentrations at the nearest house for each pollutant (*table 10*):

pollutant	nitrogen oxides	particulate matter	benzene
over-concentration at 60 m from the portal (µg/m³)	12	0,3	0,01

Table 10

(21) no threshold is laid down for benzene

5.6.5 Conclusion concerning the sensitivity of the project

At this study stage no air quality measurement has been taken on the site. As the background pollution in nitrogen dioxide and particulate matter is however monitored in a small town some fifty kilometres away, the levels measured there can be used as a first approximation of the background levels near the houses (16 µg/m³ for NO_2 and 19 µg/m³ for particulate matter). This hypothesis is unfavourable as it undoubtedly leads to an overestimation of the background level, as there is far less urban development in the study area than in the small town.

This being a rural environment the NO_2/NOx ratios given for a medium-sized town (cf. table 14) are selected as they are closer to the case being studied than those for the large urban area. This gives NO_2 / NOx = 0.89 as background (cf. paragraph 3.6), and NO_2 / NOx = 0.67 for d = 60 m and θ = 60° (cf. table 17). From this we deduce the total concentration in NO_2: $C(NO_2) = 0.67 \times (12 + 16 / 0.89) = 20$ µg/m³.

For particulate matter, we simply apply:
C(PM) = 19 + 0.3 = 19.3 µg/m³.

In the total absence of measurements in the project area for benzene, we take a background level of 1 µg/m³, this gives $C_{(C6H6)} = 1 + 0.01 \approx 1$ µg/m³. By adding the calculated over-concentration to the background pollution, we obtain the average level likely to be reached in the hamlet near one of the two tunnel portals (*table 11*), which can be compared with the threshold laid down as the quality objective in the ambient air.

pollutant	nitrogen dioxide	particulate matter	benzene
over-concentration at 60 m from the portal (µg/m³)	20	19,3	1
quality objective	40	30	2

Table 11

In all cases, concentration remains below the threshold laid down as the quality objective, we can therefore conclude that the site is not sensitive, which confirms the initial intuition.

6. THE CONTENT OF PRELIMINARY STUDIES COMPARISON OF OPTIONS

The aim of the comparison of options phase of the preliminary studies is to bring out, from all the planned routes, the option which minimises impacts on air quality.

The proposed approach is that of the *methodological note on the assessment of the health effects of air pollution in road impact studies [3]*. It consists of building, for each option, two indicators of exposure to pollution due to the project: one in relation to population, the other to vegetation and soils. As the indicators are purely comparative, they are constructed on the basis of a simplified method, which does not enable absolute levels of pollution or exposure to be calculated, but which is sufficient to produce a hierarchy of options.

6.1 PRINCIPLES OF THE PROPOSED METHOD

6.1.1 Consideration of the study level

The method of calculating pollution exposure indicators presented here is intended for level I and II studies, for which the *methodological note [3]* requires a specific study of effects on health (cf. 4.4.3) using the PPI (population - pollution exposure indicator).

For level III and IV studies, which only require basic information on the impacts of atmospheric pollution on health and no dispersion calculation, the method will not need to be used. The very simplified method presented in the previous chapter is to be used in this case.

6.1.2 Connection with the project as a whole

It should be borne in mind that the approach presented here is just one part of an overall calculation aimed at assessing whether a road project will lead to an increase or decrease in the population's exposure across the study area. The tunnel is in fact just one section of the project, which itself represents just one part of the road network to which the assessment relates (see *methodological note [3]*).

By definition, the exposure indicator concerning a tunnel created where no route was present is positive or zero. This in no way means that its impact is negative, in the first instance as a tunnel provides protection in its covered part compared with a road built in the open air, and secondly as the project of which the tunnel is a part could also lead to a significant reduction in exposure along relief routes.

Consequently, the term population exposure indicator is used, even though it only refers to the tunnel component of the project's total exposure indicator.

6.1.3 Assessment principle - constructing a gaseous pollution exposure indicator (PPI)

The indicator for the comparison of options and their tunnels is the gaseous pollution exposure indicator (PPI - see *methodological note [3]*).

As this is a comparative study the exposure calculated by means of the indicator is relative exposure, i.e. due only to the project and to its tunnel, without taking into account all the potential sources of emissions (domestic sources, industrial sources and other roads) which are identical for all the options.

This indicator reflects the total of all the individual exposures of people present in the vicinity of each tunnel option and subject to its effects, hence the term population exposure indicator.

As individual exposure corresponds to the multiplication of the received pollution dose, i.e. the level of concentration of the air inhaled by an individual, per exposure time, a dispersion modelling calculation is necessary at this stage to find the proportion of the pollution emitted by the project that is spread to the nearest houses. The recommended modelling principles for calculating the indicator are set out below.

6.2 CALCULATION OF POLLUTANT EMISSIONS AND DISTRIBUTION BETWEEN THE TWO PORTALS

Pollutant emissions are calculated according to a method similar to that used in the feasibility study stage, according to the methodology proposed in 4.2.

As in the previous chapter the traffic figures are those of an average hour of the year at the planning horizon selected for the other environmental studies.

The reference gaseous pollutant to be used in relation to effects on human health is benzene (cf. 4.4.3).

The distribution of emissions between the two portals is made in exactly the same way as that set out in the previous chapter, unless the additional factors established at this study level allow it to be refined.

6.3 CALCULATION OF DISPERSION OF GASEOUS POLLUTANTS

A dispersion calculation is required at this stage, as concentration values are needed for calculating pollution exposure indicators.

6.3.1 Selection of meteorological conditions: reconstruction of the annual average situation

Recent epidemiological studies indicate that in terms of human health, small increases in levels of pollution inhaled throughout the year are undoubtedly more harmful than high but very localised increases (peaks of pollution).

For this reason, the increase in average concentration that the project might cause in its immediate surroundings over a year should be modelled.

This leads firstly to traffic figures for an average hour of the year being taken, as set out above, and secondly the annual average weather condition being reconstructed with the aid of a wind rose obtained from a local station, over a minimum period of one year.

Reconstruction of the annual average situation consists of calculating the level of pollutant concentration for each wind rose position, then converting this into a weighted average according to occurrence. The result obtained is an estimation of the annual average concentration.

It should be stressed that this reconstruction leads to as many dispersion calculations being carried out as there are positions on the wind rose, which requires a rapid method of calculation so that the time and cost of the study remain reasonable at this preliminary stage.

6.3.2 Taking relief into account

As relief is a major factor for dispersion it should be factored into all calculations, at least in a simple way. In all cases the natural relief at portal openings, and possibly large embankments or rubble which may extend from the tunnel should be modelled.

In urban environments, adjusted models should be used for trench configurations ("street canyon"), depending on the model used.

6.3.3 Definition of the geometry of sources

Sources of linear emissions constituted by the project outside the tunnel areas are modelled by following the route on the map provided by the research department responsible for the geometric design of the project. The width is adjusted to the planned number of lanes.

Where tunnels are concerned, pollutant emissions are zero throughout the length of their covered parts, and discharges at the portals are modelled specifically, by a linear source 10 metres in length in the extension of the tunnel axis, over which the emissions produced by this portal are evenly distributed. This 10 metre length enables the discharge dynamics to be inserted very easily. The width is adjusted to the transverse profile of the lane.

6.3.4 Form of dispersion calculation results

The dispersion calculation should provide a pollutant concentration field according to a grid dense enough to take proper account of falls in pollution levels in the vicinity of the tunnel portals. This means that enough calculation points are used in an area of about a hundred metres around the portal. Beyond this the grid may be less dense.

6.3.5 Type of modelling possible: "sophisticated" gaussian dispersion method

During this comparison of options phase leading to a quantified exposure indicator, it is no longer possible to take pollution dilution into account according to the method set out for the feasibility studies. A dispersion calculation is necessary to take account of the specific features of the site and the project.

The method must nevertheless remain sufficiently simple, both in model construction time and in calculation time as there may be many options to be studied. The complexity of the model should moreover not exceed the level of definition of the project, still cursory at this stage. In view of these factors and the principles given in 4.3, a gaussian dispersion method with improvements and additions to the strict gaussian method is more suitable.

The data to be taken into account and the method of modelling are described in the following paragraphs and in the example given in 6.5.

6.4 CALCULATION OF THE POPULATION - GASEOUS POLLUTION EXPOSURE INDICATOR (PPI)

This paragraph sets out the method for moving from the average concentration field to the population exposure indicator. The use of a Geographical Information System (GIS) program is recommended for dealing with this part of the calculations, in order to be able to take into account the geometry of the project, the relief, land use (built-up areas and rugosity), etc.

6.4.1 Calculation of iso-concentration curves

From the average concentration field given by the dispersion calculation, an interpolation calculation enables iso-concentration curves to be constructed that will enable the level of concentration to be associated with each point or grid of the study area.

6.4.2 Taking account of the population

This second step consists of working out the population present in the areas where the iso-concentration calculations carried out during the previous stage show that the project will have a significant impact. During this operation, the concentration level corresponding to the area (point, grid or iso-area) where it is located should be attributed to any identified population.

6.4.3 Calculating the population exposure indicator (PPI) specific to an option

The population - pollution exposure indicator PPI for a given option is of the form:

$$PPI = \sum_{P_i} (N_i \, . C_i)$$

This formula means that the PPI exposure indicator is the total, extended to all sectors P_i of the zone of influence, of the product of the number N_i of people present in sector P_i by the concentration C_i in pollutant associated with sector P_i.

The concentration C_i in pollutant associated with each point P_i is given by the dispersion calculation. The exposure indicator is given in (number of people) x (µg/m^3 of pollutant) for an average hour of the year.

6.4.4 Comparison of options

The PPI component thus calculated for a tunnel should then be included in the total PPI over the study area.

Once the PPI has been calculated for each of the options, these may be ranked in increasing order of PPI. The option with the lowest PPI is the one that minimises the impact of the project in relation to the direct effects of gaseous pollution on human health.

As stated at the beginning of this chapter, the method is comparative and not intended to give an absolute risk assessment in terms of morbidity or mortality.

6.5 WORKED EXAMPLE

6.5.1 Presentation of the project

Let's take a motorway project that crosses an undulating area consisting mostly of agricultural land. This project will take 39,400 vehicles per day, 10 % of which are heavy goods vehicles. As the project is relatively long it is divided into several sections.

Over one of the project sections, two options are studied, each including a tunnel with two one-way tubes.

These two options (A and B) are presented in illustration 21.

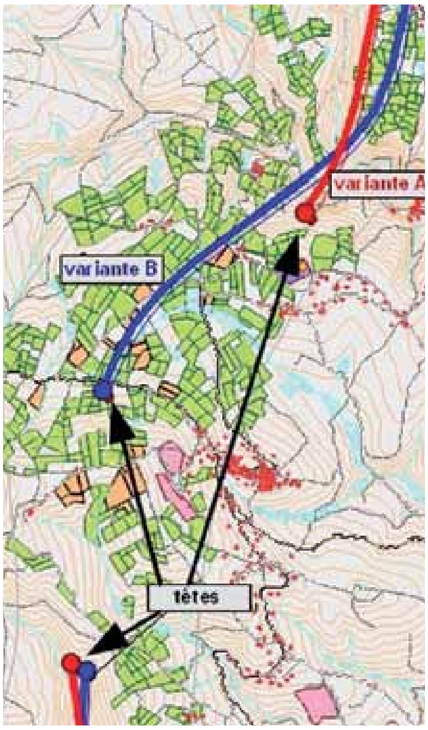


Illustration 21 - Plan view of the routes of options A and B

The aim is to identify the option which minimises impact in relation to the direct effects of gaseous pollution on human health.

The successive stages of the study are presented in the following paragraphs.

The pollutant used for calculating the population - gaseous pollution exposure indicator is benzene, in accordance with the *methodological note [3]*.

6.5.2 Calculation of pollutant emissions

The methods for calculating emissions are the usual methods for this stage of studies.

It should be noted that the planned tunnels are longitudinally ventilated one-way bi-tubes. It is therefore assumed that the benzene discharges are shared equally between the two tunnel portals, at the exit of each tube.

Inside the two tubes the total of annual average emissions, calculated according to the COPERT methodology, is as follows (*table 12*):

		benzene
option A	tube 1 (g/day)	34 955
	tube 2 (g/day)	34 955
	2 tubes (g/day)	**69 910**
option B	tube 1 (g/day)	16 556
	tube 2 (g/day)	16 556
	2 tubes (g/day)	**33 112**

Table 12

6.5.3 Gaseous pollutant dispersion calculations

6.5.3.1 Choice of modelling parameters

The parameters used for modelling pollutant emission dispersion are the weather conditions, atmospheric stability and background pollution of the site.

The average weather situation is reconstructed from 72 positions (18 directions and 4 wind strengths) weighted according to their frequency of occurrence in the course of the year. This distribution is given by the wind rose of the nearest weather station.

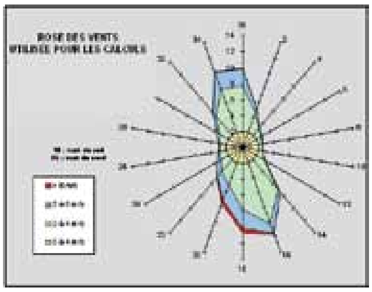


Illustration 22 - Wind rose used for calculating dispersion

Where atmospheric stability conditions are concerned, a neutral situation is chosen, described by:

- a zero heat flown exchange, $\Phi(\theta_0) = 0$ W/m²,
- a mixing layer height set at 800 metres.

A uniform ground rugosity of 0.3 metres is used. This value is representative of cultivated areas.

The background level of benzene pollution is that measured during a passive tube survey. It is equal to 2 µg/m³.

6.5.4 Dispersion calculation results: over-concentrations in benzene due to the project

The dispersion calculation results [22] are presented on the following maps, for each of the two options.

The cartographic representation only shows over-concentrations due to the project, in the form of iso-concentration curves, marked for three value levels:

- the curve of values equal to 0.5 µg/m³, in light blue
- the curve of values equal to 1 µg/m³, in blue
- the curve of values equal to 2 µg/m³, in dark blue.

6.5.5 Population exposure indicator (PPI)

The formula used for calculating the PPI was explained in the previous chapter. The formula is repeated below:

$$PPI = \sum_{P_i} (N_i \, . \, C_i)$$

The population exposed to over-concentrations as well as the level of over-concentration is determined with the aid of GIS tools[23]. This information together with the PPIs of the two options is shown in *table 13*.

	exposed population (in numbers of people)	pollution level (µg/m³)	partial PPI	PPI
option A	28	1	28	50
	11	2	22	
option B	15	1	15	15

Table 13 - PPI calculation results

It is noted that option A's exposure indicator is higher, because the population concerned is more numerous and the levels reached are higher.

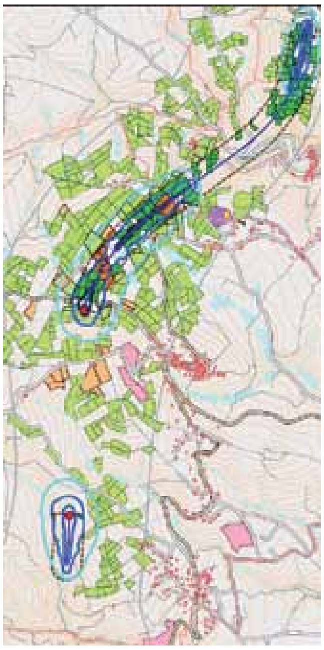


Illustration 23
Over-concentrations
in benzene – option A

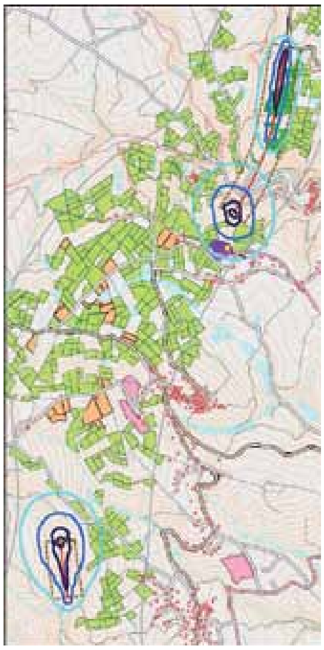


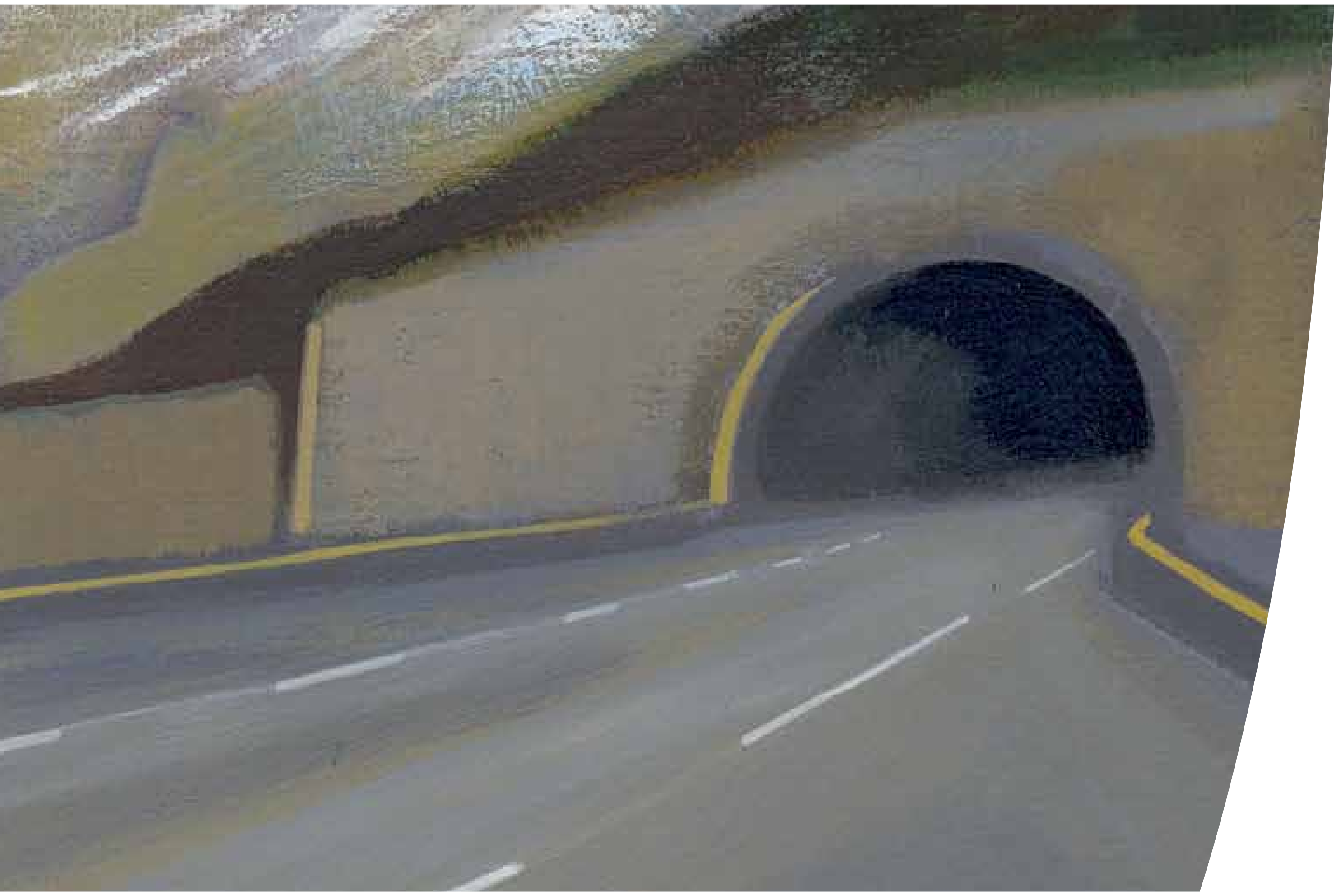
Illustration 24
Over-concentrations
in benzene – option B

(22) for this example the calculations were carried out using the ADMS software program
(23) geographical information systems

6.6 CONCLUSION

Of the two route options studied, option B, with the long tunnel, is the best from the point of view of air quality, as it leads to a lower population exposure indicator.

7. THE CONTENT OF PRELIMINARY STUDIES - STUDY OF THE PROPOSED OPTION



From the environmental point of view, at the cursory pre-project stage, the study of the proposed option implies an assessment of the project's impacts in respect of the directives, recommendations and guides in force. The positive effects of the project should be set out, as well as the measures intended to remedy its negative effects.

For this reason, unlike the previous study phase, it is no longer possible to rely on a comparative method.

It may be necessary, depending on the study level, to calculate the absolute pollution levels (concentrations) and health risks.

7.1 CONSIDERATION OF THE STUDY LEVEL

The method to be implemented for the study of the proposed option depends on the study level as defined by the *methodological note [3]*.

For level III and IV studies, which require basic information on the health impacts of atmospheric pollution and no dispersion calculation, the presence of a tunnel does not result in a special study.

For level II studies, which require a simplified study of the impacts on health and a dispersion calculation in the study strip, few additions will need to be provided in relation to the comparison of options phase set out in the previous chapter. A few factors are however given in the next paragraph.

At level I, the study carried out during the comparison of options should be supplemented by a health risk assessment.

Additions to be provided in relation to the comparison of options phase are set out in the next paragraph.

7.2 ASSESSMENT PRINCIPLES

7.2.1 Calculation of concentrations

To estimate the concentrations likely to be reached in the presence of the project and to compare them with the thresholds laid down by the French Law on Air a dispersion calculation must be carried out for level I and II studies.

The calculations may be carried out using a method similar to that presented in the previous chapter for benzene dispersion in the PPI calculation. The only differences will be the need to take background pollution into account in order to obtain an absolute concentration level, and the fact that the calculation should not be limited to benzene but should include the list of pollutants cited in 3.4.

It should be recalled that to the extent that it is nitrogen dioxide, rather than the nitrogen oxides, that is regulated, it is preferable to use modelling that enables chemical reactions to be taken into account.

When the architecture and position of the portals is known, modelling on a mock-up or with the aid of CFD software (cf. 4.3.4) could be envisaged. This is particularly the case of roofing on existing routes.

7.2.2 Health risk assessment

A health risk assessment process is mandatory for level I studies. This study should be carried out according to the instructions in 4.4.3. The pollution concentration levels needed for the health study are obtained during the concentration computations explained in the previous paragraph.

7.3 CONCLUSIONS

Even if during the study phase of the proposed solution it is no longer a matter of purely comparative reasoning but of assessing the project's absolute impacts on its surroundings, it should be borne in mind that the impact of a tunnel constitutes just one part of the total impact, and that all the other effects of the project, positive or negative, should be considered in the interpretation of the results.

However, if it appears that the tunnel is in danger of causing an unacceptable deterioration in the air quality in the area around one of its portals, measures to reduce its impact may be planned.

The first measure is to try to move the site of the portal posing the problem to a less sensitive area from the air quality point of view.

Another possible measure is to study the benefits that could be made by improving the tunnel ventilation, in order to reduce the initial discharge concentration.

An extraction shaft could possibly be used for normal operation to reduce the quantity of pollutants discharged by the portals. At this stage the feasibility of installing an extraction shaft (possibility of finding a site, quantities to extract in order to reach an acceptable impact level) should be considered without carrying out an in-depth study, which will come later, at the project stage, when the route has been properly specified. For this precise study a detailed model capable of considering very localised effects (cf. 4.3) will be used.

GLOSSARY AND LIST OF ACRONYMS

"TUNNELS" DOMAIN

Ventilation section

A ventilation section is a transversally ventilated section of tunnel in which air injection and extraction regimes can be controlled independently of the other sections.

Ventilation duct

Ventilation ducts are pipes used to convey fresh or polluted air. Air circulates in these ducts by means of acceleration supplied by the fans in the ventilation plant. There are two kinds of ventilation duct:

- those used to connect fresh air (FA) injection or polluted air (PA) extraction points in the tunnel to a ventilation unit;
- and those that enable a ventilation unit to be connected to the outside of the tunnel to take in fresh air or discharge polluted air. In the case of transversal ventilation, two ventilation ducts are needed over the length of the structure: one for fresh air and the other for polluted air. The position of ventilation ducts, in the ceiling or under the roadway, varies according to the situation and in particular the geometry of the tunnel excavation.

Ventilation unit (or plant)

A ventilation unit (or plant) is a mechanical unit made up of one or more motors operating one or more fans with the purpose of accelerating the air.

A ventilation unit is usually necessary when the ventilation system is transverse (partial transverse, semi-transverse or pure transverse) or when mass extraction is present. There are then several ventilation units per tunnel; they may be underground or in the open. In the case of mass extraction in longitudinal ventilation, the ventilation unit will be located near the extraction point.

A ventilation unit should be connected to the outside via ventilation ducts, either to take in fresh air (FA) or to discharge polluted air (PA). When a polluted air discharge station is planned for a project its installation should be analysed from the environmental point of view.

Urban tunnel

The technical instruction of 25 August 2000 [13] defines an urban tunnel as a tunnel situated inside an urban unit of more than 20,000 residents (according to the INSEE definition) and satisfying at least one of the following conditions:

- expected traffic in one direction greater than 1,000 vehicles per traffic lane at rush hour, ten years after commissioning;
- risk of queues in tunnels linked to the presence of a junction without an interchange shortly after the structure exit, or to any other permanent device (densely built-up area crossing, etc.);
- presence in the tunnel of interchanges, pedestrian, public transport or service lanes (e.g. car park or building entrance situated in the tunnel), etc.

Tunnels situated in urban units of less than 20,000 people in which there is frequent risk of congestion are also considered urban.

In this document the term "urban tunnel" is used according to this definition.

Non-urban tunnel

A non-urban tunnel as defined in the *technical instruction of 25 August 2000 [13]* is a tunnel that does not satisfy the conditions enabling it to be considered urban.

Low traffic tunnel

A low traffic tunnel within the meaning of the *technical instruction of 25 August 2000 [13]* is a tunnel in which the expected traffic in each direction, ten years after commissioning, is less than an average of 2,000 vehicles per day per year and 400 vehicles per hour at rush hour (defined as the thirtieth busiest hour of the year). To apply this criterion, one HGV counts as five vehicles.

"HEALTH" DOMAIN

Maximum allowable concentration in the air (MAC)

The maximum allowable concentration in the air is the human health toxicity value (HHTV) used for threshold level toxic effects when the respiratory tract is the exposure route. It is expressed in mg or µg/m³ (milligram or microgram of chemical substance per cubic metre of ambient air). MAC defines for a specified exposure period the theoretical maximum content of a toxic agent in the ambient air that an individual, whether from a sensitive group or not, can inhale without any adverse effects to his or her health.

Average concentration in the air (AC)

The average concentration in the air is an estimation of the average toxic agent concentration in the ambient air taking account of exposure methods. It is expressed in the same units as the MAC.

Danger

An undesirable health event such as an illness, trauma, disability or death. By extension danger means any toxic effect, i.e. an organic or cellular dysfunction linked to the interaction between a living organism and a physical, chemical or biological agent.

Determinist

Describes toxic effects whose severity is proportional to the dose. Conventionally, deterministic effects only occur if a threshold is reached and exceeds the organism's detoxification, repair or compensation capacities.

Determination of the dose - response ratio

This second stage of the health risk assessment is an estimation of the probability of these dangers occurring. It is a matter of characterising (qualifying and quantifying) the link between the dose (or exposure) and the effect. Up till now this mathematical ratio was often achieved by extrapolating low doses (which characterise environmental pollution and for which the effect is more difficult to measure) from the results of high dose tests on animals. The most recent and important development of epidemiological knowledge in the domain of atmospheric pollution now, at least in certain domains, permits the uncertainty linked to extrapolation to be reduced.

Dose

Quantity of dangerous agent coming in contact with a living organism. It is expressed in milligrams per kilo body weight per day.

Acute effect

Problems linked to a short but high dose. They are generally immediate or occur in the short term (a few hours to a few days) and disappear spontaneously when the exposure stops, unless irreversible problems have been caused.

Chronic effect

Problems related to low but prolonged exposure. These generally occur with a latent period which can be several months or even decades and are usually irreversible without treatment.

Carcinogenic effect

Toxicity which is manifested by the appearance of cancers.

Systemic effect

Toxicity of a polluting agent manifesting itself by a non-cancerous problem in tissue or a function.

Assessment of exposure

This stage of the health risk exposure assessment process is intended to quantify exposure (to which concentrations and for how long) to which the population (who and how many people) is subject.

Excess risk (ER)

Additional risk due to specific exposure compared with the risk in a reference population (in general not exposed).

Excess individual risk (EIR)

Probability of an occurrence (of a danger occurring), in the course of the lifetime of an individual, linked to exposure to a carcinogenic agent.

Excess unitary risk (EUR)

Estimation of the EIR for a "lifetime" exposure equal to a unit dose of a dangerous agent. This index is the human health toxicity value (HHTV) for carcinogenic toxins. It generally represents the upper slope of the confidence interval of the dose-response curve and is expressed, for exposure by respiratory tract route, in $(\mu g/m^3)^{-1}$.

For example: $Benzene_{inhalation}$ EUR = $6x10^{-6}$ (mg/m^3): this figure means that exposure via inhalation of one million people during a lifetime (70 years, 24 hours per day) at the concentration of 1 mg/m^3 of benzene is likely to induce 6 extra deaths from leukaemia.

Excess collective risk (ECR)

Also called "impact", this represents an estimation of the number of excess cancers, linked to a studied exposure, which should occur in the life of this group of individuals.

Exposure

Means, in the health domain, contact between a dangerous situation or agent and a living organism. The exposure can be considered as the concentration of a dangerous agent in the polluted environment(s) coming into contact with man.

Acute exposure
Exposure of a few seconds to a few days.

Chronic exposure
Exposure of a few years to a lifetime.

Sub-chronic exposure
Exposure of a few days to a few years.

Identification of dangers

This is the determination of the harmful effects of physical, chemical or biological agents. This response is based on interpretation of the results of medical observations and epidemiological and toxicological studies. It enables a list of dangers possibly linked to a pollutant to be drawn up, together with a qualitative judgement on the scientific probability of the effect. Ideally epidemiological observations are undertaken in man. If not, test results (on animals) can be used.

Risk quotient

Relationship between the estimation of an exposure (expressed by a dose or concentration for a specified period of time) and the HHTV of the dangerous agent for the corresponding exposure route and time. The RQ (without unit) is not a probability and only concerns threshold effects.

Risk

Probability of a cancer occurring.

Characterisation of the risk

This final stage of the health risk assessment process constitutes the summary stage which combines exposure and dose-response data. It includes a total estimate of the excess risk linked to the pollutants (estimation of the health impact), associated with an explanation of uncertainties. The risk analysis consists of a summary of scientific knowledge, an optimal situation of available data and modelling enabling decisions to be guided in a situation of uncertainty. It also enables the domains in which knowledge or data is most lacking to be identified. In quantitative terms the risk is expressed by an interval ranging from 0 (representing certainty that no danger will appear) to 1 (representing the certainty that a danger will appear).

Threshold

The dose or exposure below which no adverse effect is expected. Threshold effect substances (with some exceptions, systemic toxins) and non-threshold effect substances (carcinogens) can be distinguished.

Stochastic

Qualifies a toxic effect whose frequency, but not severity is proportional to the dose. Stochastic effects, cancers, mutations are known to be able to appear whatever the dose received by the organism (no threshold).

HHTV
(Human health toxicity value)

Generic name for all types of toxicological indicators which enable a relationship to be established between a dose and an effect (threshold effect toxicity) or between a dose and a probability of effects (non-threshold effect toxicity). HHTVs are established by international authorities (such as the WHO or the CIPR) or national bodies (US-EPA and ATSDR in the United States, RIVM in the Netherlands, Health Canada, CSHPF in France, etc.).

THEMATIC BIBLIOGRAPHY

Bibliographical references are presented here under four subject headings:
- "Environment and air quality",
- "Health",
- "Tunnels",
- "Road transport and preparation of road projects".

For this reason the order of presentation is different from the numerical order.

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APPENDIX: SIMPLIFIED MODEL FOR ESTIMATING THE NO_2/ NOX

This appendix puts forward a summary of the modelling method described in detail in the 2004-19 report *"Estimation of average NO_2/NOx ratios in the vicinity of the mouth of a cut-and-cover in an urban environment" [35]*

The method implemented by CEREA firstly consisted of studying the different pollution situations encountered in a town, based on measurements taken continuously over a long period (database from approved air quality monitoring associations). At the end of this statistical study three typical urban pollution situations were characterised:

- Type 1 situations : characterised by high ozone content, while concentrations for the other pollutants are lower than the average values;
- Type 2 situations: intermediate situations for which the concentrations measured remain quite close to average values;
- Type 3 situations: characterised by extremely high concentrations for the primary pollutants and very low ozone content.

For information, the average background concentrations calculated for these three typical situations are given in the tables below, for the two scenarios tested:

- table 14: large urban area [24],
- table 15: medium-sized town [25].

situation type	type 1: high O_3 content	type 2: intermediate situations	type 3: low O_3 content
background NO	4 µg/m³	22 µg/m³	92 µg/m³
NO_2 background	29 µg/m³	75 µg/m³	100 µg/m³
O_3 background	59 µg/m³	20 µg/m³	9 µg/m³
NO_2/NOx background	0,84	0,69	0,33

Table 14 - Estimation of average background concentrations - large urban area

situation type	type 1: high O_3 content	type 2: intermediate situations	type 3: low O_3 content
background NO	1 µg/m³	4 µg/m³	12 µg/m³
NO_2 background	17 µg/m³	30 µg/m³	66 µg/m³
O_3 background	69 µg/m³	41 µg/m³	20 µg/m³
NO_2/NOx background	0,92	0,83	0,78

Table 14 - Estimation of background concentrations - medium-sized town

Considering the frequencies of occurrence of the three situation types, the average background NO_2/NOx ratio is 0.76 for the large urban area and 0.89 for the medium-sized town.

Once the three characteristic situations have been defined the method implemented by CEREA consisted of calculating the NO_2/NOx ratio for the points subjected to the impact of the discharge. The calculation was carried out for each of the three situations, using a simplified reactive model with the passive dilution coefficients given in the test report *Mock-up study of a dispersion scenario at a tunnel portal [36]* (see also 5.4). The results were then weighted by the frequency of occurrence of the different pollution situations.

As a result the values obtained enable an order of magnitude to be estimated for the NO_2/NOx ratio for an average situation. On the other hand they cannot be used to characterise a particular situation (especially a particularly unfavourable situation).

The change in the NO_2/NOx ratio according to distance from the tunnel portal was calculated for the two test scenarios:

- large urban area with high background pollution in nitrogen oxides,
- medium-sized town with low pollution in nitrogen oxides.

(24) the scenario was constructed from data measured in the Paris region (AIRPARIF data)
(25) the scenario was constructed from data measured in the Orleans region (LIGAIR data)

The NO_2/NOx ratios obtained in a point situated near the discharge are given in the tables below. They vary according to the position of the point in relation to the tunnel portal. This position is defined by the angle *θ* and the distance *d*, *θ* giving the direction of the point in relation to the direction of the discharge, and *d* being the distance between the point and the tunnel portal (see illustration 25).

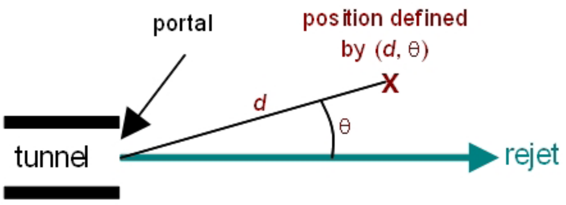

Illustration 25

Examination of tables 16 and 17 shows that the NO_2/NOx ratio increases rapidly with distance from the discharge.

At 150 metres from the portal, except in the tunnel axis, the impact of the discharge is almost no longer felt. At this distance the ratio has returned to values close to the background NO_2/NOx ratio:

- at about 0.7 in the case of the large urban area, or $(NO_2/NOx)_{[background]} = 0.76$,
- at about 0.85 in the case of the medium-sized town, or $(NO_2/NOx)_{[background]} = 0.89$.

ratio NO_2/NOx	distance d from the tunnel portal			
angle θ	25 m	50 m	100 m	150 m
0°	0,23	0,25	0,31	0,47
30°	0,29	0,48	0,64	0,71
60°	0,34	0,55	0,68	0,72
90°	0,34	0,55	0,67	0,72
120°	0,34	0,51	0,65	0,71
150°	0,28	0,43	0,60	0,71
180°	0,22	0,25	0,44	0,69

Table 16 - Estimation of the NO_2/NOx ratio of tunnel discharge in the case of a large urban area for which $NO_2/NOx_{[background]average} = 0.76$

ratio NO_2/NOx	distance d from the tunnel portal			
angle θ	25 m	50 m	100 m	150 m
0°	0,23	0,25	0,32	0,54
30°	0,31	0,56	0,78	0,85
60°	0,37	0,67	0,82	0,86
90°	0,37	0,67	0,82	0,86
120°	0,37	0,61	0,79	0,86
150°	0,29	0,48	0,74	0,85
180°	0,23	0,25	0,50	0,83

Table 17 - Estimation of the NO_2/NOx ratio of tunnel discharge in the case of a medium-sized town for which $NO_2/NOx_{[background]average} = 0.89$

The NO_2/NOx ratios used above come from the first results of the study undertaken by CEREA on the reactive dispersion of nitrogen oxides near tunnel portals. Research in this field will be more in-depth in order to better validate the current results and correct them if necessary. The values used here are therefore likely to be amended in the future.

NOTES

NOTES

NOTES

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