Guide to Road Tunnel Safety Documentation

Booklet 3

Risks analyses relating to dangerous goods transport

December 2005
Guide to Road Tunnel Safety Documentation

For every tunnel in the national road network whose length is over 300 metres, safety documentation is to be compiled and submitted to the prefect. The procedures regarding the documents to be included in this package are subject to regulations.

All persons and services involved in tunnel safety (the owner, the operator, the maintenance and repair and emergency services, the prefecture) must assist with the compilation of this dossier which, in its final version, will contain among other things the essential aspects of tunnel operation under any and all circumstances.

This safety documentation guide is intended for the above services, the owner and the relevant consultants.

The introductory document "Safety Documentation Objectives" was issued in March 2003; it should be read by every person required to understand the general intent of the recommended procedures and how the various documents contained in the safety documentation are organised.

The safety documentation guide, of which the above-mentioned introductory document may be regarded as "booklet 0", comprises the following five booklets, which have either already been issued or are due to be issued in the future:

• Booklet 1: Practical method of compiling the safety documentation
• Booklet 2: Tunnels in Operation: "From the Existing Condition to the Reference Condition" (June 2003);
• Booklet 3: Risks analyses relating to dangerous goods transport;
• Booklet 4: Specific hazard investigations (September 2003);
• Booklet 5: Emergency response plan.

Statutory background

• Inter-ministerial circular no. 2000-63 of 25 August 2000 concerning the safety of tunnels in the national road network requires the owner (jointly with the operator in the case of tunnels in service) to compile safety documentation for all tunnels in the national road network of over 300 metres in length.


• Decree no. 2005-701 of 24 June 2005, implementing the law of 3 January 2002 relating to the safety of infrastructures and transport systems which confirms this requirement and extends it to all local authority tunnels of over 300 metres in length.

• Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004, also confirms this requirement, specifies the responsibilities of stakeholders and defines the minimum requirements applicable to tunnels on the Trans European road network which are over 500 metres in length.
Introduction

Accidents involving hazardous goods, in particular toxic, flammable and/or explosive goods, are very rare. However, these kinds of accidents can cause major incidents which are much more severe in tunnels than in the open air. For this reason the decision whether to allow vehicles transporting dangerous goods (TDG) to enter tunnels can only be made after an objective assessment of the risks.

The method adopted consists of assessing the risks for the human beings who use and live close to the tunnels by modelling the frequency of accidents and the severity of the consequences of these accidents. The risk assessments are performed using specific QRA (Quantitative Risk Assessment) software.

This booklet describes the method in a simple and practical manner. It also indicates the various measures which can be taken to reduce risks in tunnels if hazardous goods have to be transported through them. These measures are both preventive (aimed at reducing the probability of an accident) and protective (aimed at reducing the consequences if an accident still occurs).

Interested readers will find additional information on the method adopted and the reasons for using it in the appendixes.

It has been approved by the CESTR (Comité d’Évaluation de la Sécurité des Tunnels Routiers / road tunnel safety assessment committee) and will continue to be applied with future regulations which are currently under preparation.

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1 Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 requires the performance of a risk analysis. As this directive is incorporated into French law, this analysis will include the risk analysis associated with the transport of dangerous goods specified in section 3.7 of Annex 1 and the specific hazard survey. The initial title of this booklet ("comparative risk analyses") has been changed in order to ensure consistency with the European directive.
1. Issues involved in the transport of dangerous goods (TDG)

1.1 General regulation applicable to the transport of dangerous goods

In France, movement of dangerous goods represent approximately 5% of all heavy goods traffic. Dangerous goods and the risks associated with them vary considerably. The following table shows the international classification for dangerous goods, together with examples of labels attached to them (other labels are also used for certain classes depending on the hazards presented by the goods).

<table>
<thead>
<tr>
<th>Class</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Explosive substances and articles</td>
<td>5.1 Oxidizing substances</td>
</tr>
<tr>
<td></td>
<td>5.2 Organic peroxides</td>
</tr>
<tr>
<td>2. Gases</td>
<td>6.1 Toxic substances</td>
</tr>
<tr>
<td>3. Flammable liquids</td>
<td>6.2 Infectious substances</td>
</tr>
<tr>
<td>4.1 Flammable solids, self-reactive</td>
<td>7 Radioactive material</td>
</tr>
<tr>
<td>substances and solid desensitized explosives</td>
<td></td>
</tr>
<tr>
<td>4.2 Substances liable to spontaneous</td>
<td>8 Corrosive substances</td>
</tr>
<tr>
<td>combustion</td>
<td></td>
</tr>
<tr>
<td>4.3 Substances which, in contact with water,</td>
<td>9 Miscellaneous dangerous substances</td>
</tr>
<tr>
<td>emit flammable gases</td>
<td></td>
</tr>
</tbody>
</table>

Classification of dangerous goods and examples of labels

Vehicles carrying dangerous goods suffer comparatively fewer accidents than other HGVs, as the drivers are better trained and the vehicles are serviced more carefully. The average severity of accidents is broadly similar, in terms of the number of casualty accidents in relation to the total number of accidents, the number of fatalities as a proportion of casualty accidents, and so on. There are therefore relatively few accidents involving the transport of dangerous goods in France.
The total number is around 200 per year for the entire road network, causing twenty or so fatalities. Most of these are traffic accidents in which the dangerous goods are neither the cause nor an aggravating factor.

However, even if accidents involving the dangerous goods carried are fortunately very rare, a limited number of substances can produce very serious accidents, such as explosions caused by inflammable gases or liquids, violent fires, release of toxic gas, etc. In France, thirteen people died as a result of a collision between a train and a road tanker carrying hydrocarbons at a level crossing at Port-Sainte-Foy in 1997. In western Europe, the most serious accident involving the transport of dangerous goods by road in recent decades occurred at Los Alfaques in Spain on 12 July 1978, when 216 were killed when an articulated propylene tanker exploded on a road running alongside a camping site.

Specific international regulations apply to the transport of dangerous goods due to the hazardous nature of the material carried. These are contained in the ADR\(^1\), drafted by the United Nations Economic Commission for Europe in Geneva (UNECE). This international agreement has become mandatory inside the European Union for transportation within international member states and for international transport. The French regulations\(^2\) therefore incorporate the ADR and include a number of additions and clarifications.

The regulations assign a four-digit number to each substance, known as the "UN number", and classify dangerous goods according to the risk associated with them (see table above). The regulations specify technical requirements and set out rules concerning containers (packing, tanks, bulk containers, etc.). They provide the rules applicable to the certification of vehicles which are subject to specific requirements relating to electrical circuits, braking systems, fire extinguishers, etc. which are additional to the requirements of the "Code de la Route" (the French Highway Code), and prescribe the content of the vehicles annual inspection. They also specify consignment procedures, including marking and labelling of packages, placarding and placing orange plates on containers, removable tanks, vehicles, documentation and so on. The ADR regulations also cover the training of persons involved in TDG, in particular road vehicle drivers, as well as the way in which companies organize transport safety matters - for example, companies must appoint a qualified safety advisor. Loading and unloading conditions are also subject to the regulations, which also specify the safety duties of the parties concerned in the transport chain, i.e. carriers, loaders, etc.

When the context requires, the regulations provide for the establishment of local prohibitions on certain routes in order to take account of particularly significant local vulnerabilities. Naturally enough, signs have to be used to inform users of local prohibitions of this kind, in accordance with the "Code de la Route". The three road signs currently available for this purpose are shown below.

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1 Agreement concerning the international carriage of Dangerous goods by Road
2 Order dated 01/06/2001 (amended), known in France as the "arrêté ADR".
<table>
<thead>
<tr>
<th>B18a</th>
<th>Access prohibited to vehicles transporting over a specific quantity of explosive or easily flammable goods and which bear appropriate signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>B18b</td>
<td>Access prohibited to vehicles transporting over a specific quantity of goods which may pollute water and which bear appropriate signs</td>
</tr>
<tr>
<td>B18c</td>
<td>Access prohibited to vehicles transporting dangerous goods and which bear appropriate signs</td>
</tr>
</tbody>
</table>

Road signs prohibiting all or some TDG movements

Example of signs affixed to a vehicle transporting dangerous goods:
- Green label (gas)
- Yellow label (oxidising substances, organic peroxides)
- Orange plate (UN n°).

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3 Refer to article 10 of Order dated 01/06/2001 (amended) for further details. This order is known as the "arrêté ADR" in France.
1.2 Special considerations regarding tunnels for TDG

The consequences of accidents involving dangerous goods can be more serious inside tunnels due to confined space within the structure\(^4\).

The major hazards which could lead to heavy casualties in a tunnel, and possibly cause severe damage to the infrastructure, are chiefly associated with the following:

- **Explosions**: The most feared types of accident include fireballs created by the explosion of an LPG tank after it has been heated in a fire, or the explosion of a cloud of flammable gas released by a leaking tank. Phenomena of this kind can lead to the death of all people inside the tunnel and in the immediate surrounding area.

- **Large-scale release of toxic gas**: This type of release can be due to a breach on a tank containing a toxic gas or volatile toxic liquid. This can not only kill anyone close to the leak, but also people located in areas where air currents may propel the gases, including areas outside the tunnel.

- **Violent fires**: Petrol tank fires for example can produce considerable quantities of smoke, toxic gases and heat (see appendix C of booklet 4 on Specific hazard investigations). Depending on the type of tunnel, it may be very difficult to protect other users from the effects of a fire of this sort and there may be a large number of casualties.

Since the consequences are more serious than in the open air, there are grounds for asking whether TDG movements should be prohibited in tunnels.

The existence of an alternative route which is entirely in the open air is not, in itself, grounds for prohibiting TDG movements in tunnels. Other factors may apply, such as:

- the alternative route may contain areas which are densely populated where certain TDG accidents could have disastrous consequences, whereas the route through the tunnel runs through sparsely populated areas,

- the alternative route may take the vehicle through more accident-causing situations than the route via the tunnel: one of the reasons for creating the tunnel could well have been that it offered much better road safety characteristics.

\(^4\) On the other hand, the consequences of accident involving some dangerous goods, such as corrosive substances for example, are not made more serious by containment.
Decisions whether to allow or prohibit some or all TDG movements in tunnels should therefore be based on a **comparison between the risks associated with each route**.

These comparisons are difficult to make with great certainty, as:

✔ the probability of the disasters in question occurring is very low,

✔ the average annual number of casualties associated with these disasters is both extremely low (much lower than the number of road accident casualties), and the numbers for a single one-off accident can be very high,

✔ the distribution of casualties among users and the local population varies depending on whether the route is in the open air or in a tunnel.

It is recommended that the method described in this booklet is used to avoid making arbitrary decision on whether to prohibit or allow the transport of dangerous goods in tunnels.

**It must be possible to indicate the system adopted** in accordance with the Code de la Route. Of the signs indicated earlier, B18a and B18c are the only two which are relevant to tunnels. This means that three operating modes are currently available:

✔ authorisation for all vehicles transporting dangerous goods (no sign),

✔ prohibition of vehicles transporting more than a specific quantity of explosive or easily flammable products (sign B18a),

✔ prohibition of all vehicles transporting dangerous goods and bearing appropriate sign (sign B18c).

However, if the tunnel is subject to routine checks at the entrance and has parking areas where these checks can be performed, specific regulations relating to different dangerous goods may be considered. It may also be possible to arrange for the movements of dangerous goods to be escorted by one or more vehicles.

If TDG movements are authorized in the tunnel, some or all of the measures described in chapter 5 below may be implemented to reduce the level of risks: some of these measures are mandatory in new tunnels.

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5 The UNECE is currently working on increasing the number of TDG groupings from three to five, which would make the regulations more easily adaptable to the specific risks associated with each tunnel.
2. Principles used in the analysis of risks associated with TDG

It is useful to restate how the question relates to individual tunnels:

Does the comparative risk analysis comparing the route including the tunnel against one or more alternative routes give grounds for authorizing some or all TDG movements to pass through the tunnel?

2.1 The quantitative risk assessment model

Risks are assessed by means of the quantitative risk assessment model (QRA model)\(^1\) developed under the joint research project conducted by the OECD\(^2\) and PIARC\(^3\), with financial backing from the European Union. Since this model is subject to change, the version used must be the version approved by the CETU at the time the study is performed\(^4\).

The model can be obtained from PIARC; either PIARC or the CETU can indicate organizations which can provide technical assistance or give training to users. In view of the complexity of the model, its use must be restricted to people who possess risk analysis skills and have received training in using the model.

The QRA model quantifies both aspects of the risk: the probability of the occurrence of events and the severity of the consequences of these events. Severity can be expressed in terms of loss of human life, injuries, the destruction buildings or structures or damage to the environment. Although the model provides data on all these aspects, the method described here only uses results relating to fatalities.

A full TDG risk assessment would require the study of all accident scenarios which could occur. It would therefore need to examine all possible weather conditions, all possible accident types and all kinds of vehicles, both fully laden and part-loaded, possibly vehicles in breach of the regulations, and so on. An assessment of this kind would be totally impractical, and so some simplification has been introduced.

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\(^1\) The model was developed and created by INERIS (France), W.S. Atkins (U.K.) and IRR (Canada)
\(^2\) The Organisation for Economic Co-operation and Development (website: www.oecd.org)
\(^3\) World Road Association (website: www.piarc.org)
\(^4\) At the date of publication of this booklet, the current version is version 3.60
The model is built on the following basis:

✔ selection of a limited number of representative dangerous goods,

✔ selection of a few representative serious accident scenarios involving these goods which could occur at any point on the route,

✔ determination of the probabilities of the occurrence of these events,

✔ assessment of the effects of these scenarios on the users of the route and on the local population.

The simplest way of using the results produced by the model is to multiply the number of deaths arising from each accident scenario considered by the annual probability of its occurrence, and then adding the figures up for all scenarios: the weighted average obtained is called the "expected value", denoted "EV". The EV represents the average annual number of fatalities caused by accidents involving hazardous goods.

We will see that in certain cases, the EV value is sufficient on its own, but the model can also provide results which allow a more detailed analysis to be made. It can plot F/N curves which indicate the annual frequency (F) of having an accident producing N or more fatalities. These curves can either be obtained for the entire route or for each type of goods transported. They allow the analyst to:

✔ determine the proportion of accidents which lead to multiple casualties on each route, if necessary for each group of dangerous goods;

✔ compare curves for different routes, although this comparison is not really meaningful unless there is a significant difference in the EV values for each route; this comparison provides a means of considering the impact of applying partial restrictions on TDG traffic;

✔ identify the contribution which each type of goods or accident makes to the overall EV figure.

Further details on the QRA model and its use are given in appendix A.

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5 The EV is the result of combining a large number of possible events, some of which involve few fatalities and other, much less probable ones leading to a great loss of life. Two points need to be made clear:

- if one event causes ten times as many fatalities as an other event, but is ten less likely to occur, both events will have the same EV weighting;

- if an event has an annual probability of one in a thousand, the probability of this accident remains the same every year, regardless of whether an accident of this kind occurred the year before. If there had been one, this obviously wouldn't mean that the next one wouldn't happen for another thousand years. The only thing we can say is that over a very long period, the number of accidents of this type divided by the length of the period would be close to 1/1000 (and would be 1/1000 over an infinite period).


2.2 A two-stage risk assessment process

The method starts simply and then becomes more complex. It consists of two stages with the results of the first stage determining whether it is useful to conduct a more thorough risk assessment in the second stage. There are even cases where the first stage is not performed at all: these are indicated in paragraph 2.3.

The same QRA model is used in both stages, but much more data is used in the second.

Stage 1: Assess tunnel's intrinsic risk and determine whether alternative routes exist.

Only a limited amount of data is gathered at this stage (characteristics of the tunnel and the traffic using it, plus some meteorological data). The owner confirms this data and has the tunnel's intrinsic risk (IR) calculated using the QRA model.

If the intrinsic risk is low, the tunnel itself can be considered as not constituting a special factor as far as the level of risk is concerned and is therefore not a criterion for selecting the TDG grouping for the route; there is therefore no practical purpose in pursuing analysis of TDG risks for the tunnel.

If the tunnel's intrinsic risk is not low, it will be necessary to look into whether there are one or more alternative routes for the TDG movements. In exceptional cases, there may be no alternative route and the tunnel is the only choice. The analysis will then concentrate on the measures to be taken to limit the risk (see chapter 5). If there is at least one alternative route, the assessment can proceed to the next stage.

Stage 2: Compare routes

This stage is only performed if the results of stage 1 show that it is useful to do so. A large amount of further data needs to be collected to define the characteristics of the route on which the tunnel is located and the characteristics of each of the alternative routes. This work needs to be carried out by a specialist consultancy.

The first step is to examine the results provided by the QRA model on the basis of the EV for the number of fatalities. In some instances, this criterion alone is sufficient to decide between different routes, although further criteria may need to be applied in other cases.

2.3 Cases where the risk analysis is not useful

If, for some reason, it is unlikely that TDG movements will be made through the tunnel, there is no reason to perform the risk analysis. There are distinct two possibilities here:
Possibility 1:
An existing or future tunnel is on a route on which **TDG movements are prohibited in any case, for reasons which are not directly related to the tunnel itself.** In this case, there is a de facto ban on TDG movements in the tunnel.

Possibility 2:
**Prior regulations already prohibit TDG movements in an existing tunnel, and there is no desire to remove this ban.** Strictly speaking, it would be possible to review and compare the different regulations as described above, although the risk analysis would not serve any useful purpose if there was no desire to change the TDG grouping.

### 2.4 Usefulness of the TDG risk analysis

When a tunnel is first planned, it is recommended that the system to be applied for TDG movements is examined at the preliminary design stage to provide a basis for a choice to be made at as early a point as possible. This choice is to be confirmed at the project stage when the TDG risk analysis is mandatory. The prohibition or authorisation of TDG movements is actually a determining factor in the choice of certain tunnel features, such as a continuous slotted drainage channel for taking dangerous liquids, ventilation capacity, and so on.

**Caution:**

The risk analysis associated with the transport of dangerous goods must be based on the type of tunnel which is finally selected at the end of the initial preliminary design stage.

Although it may be tempting to use this method to compare different types of tunnel, the practice is not recommended, as the simplification applied in this type of modelling process means that the QRA model is not suitable for determining optimal parameters or for making a comparative analysis of smoke extraction and ventilation systems. The model is intended for a specific use, and this kind of approach would be very incomplete, as it doesn't incorporate other risk factors like road accident statistics and fires which are not connected with the TDG.

The analysis of TDG risks must be undertaken before the specific hazard investigations so that these investigations can be based on a choice on authorized TDG grouping which has already been validated. Additionally, if the TDG risk analysis shows that dangerous goods other than liquid hydrocarbons contribute significantly to the TDG risk, it will be necessary to consider whether it is appropriate to take account of the trigger events endangering these goods in the specific hazard investigation (see booklet 4 - specific hazard investigations).

In any event, the TDG risk analysis starts with the owner's detailed analysis of current or projected TDG traffic in the tunnel.

It is recommended that the owner proceeds with stage 1 as soon as possible, as the results will determine whether to seek the services of a consultancy for stage 2.
2.5 Summary

An analysis of the risks associated with the transport of dangerous goods needs to be performed when the safety documentation is drawn up or updated:

✔ for all new tunnels over 300 metres in length, unless TDG movements are already prohibited on the route on which the tunnel is located for reasons which are not directly related to the presence of the tunnel itself,

✔ for tunnels in operation which are over 300 metres in length and in which TDG movements are currently authorized or are expected to be authorized following a change in the traffic regulations.

The first phase of the analysis of the risks associated with the transport of dangerous goods has to be performed in all of these cases. The first stage is described in further detail in chapter 3.

It then may or may not be necessary to continue to the second stage. The second stage is described in chapter 4.

The next page contains a flowchart showing the tasks to be performed, who is to perform these tasks and the decisions to be taken by the owner.
3. Content of stage 1 (intrinsic risk and alternative route)

Before work can start on any comparative risk analysis on routes, it is important to know whether the values of the factors involved are sufficiently large for the comparison to be significant. The first step is to establish the value of the intrinsic risk (IR). This is the expected value (EV) for the number of fatalities due to accidents involving dangerous goods occurring inside the tunnel itself, assuming that the tunnel places no restrictions on the transport of dangerous goods. This value is calculated using the QRA software.

The IR is calculated by an appropriate agency using data which has been collected and validated by the owner. The agency submits the result to the owner, together with a sensitivity analysis which adjusts the values of the most important parameters. Information on how to perform this calculation is available from the CETU, upon request.

The IR is then compared against a reference threshold value which the CESTR has set at one in a thousand.\(^1\)\(^2\)

If the IR value is below this threshold, TDG movements in the tunnel can be considered to constitute a low level of risk in absolute terms and that the existence of the tunnel has no impact on the TDG regulations for the route. There is therefore no need to go on to stage 2.

The owner will need to examine the results of the sensitivity analysis before establishing whether the IR is below the threshold. If the IR value is close to the threshold and if it then exceeds the threshold significantly when some of the data is adjusted within plausible limits, it is recommended that the owner considers that the IR is not below the threshold. This will mean that the owner will not be forced to carry out stage 2 and perhaps have to reconsider choices which have already been made if the threshold is exceeded later if changes are made to the project or if traffic increases.

There are two possibilities if the IR value is above the threshold:

- either, in exceptional cases, the owner establishes that there is no alternative route and the authority responsible for the traffic police confirms this, in this case, stage 2 is not carried out, but it will still be necessary to examine measures which could reduce risks in the tunnel (see chapter 5) as TDG traffic will be obliged to use it;
- or there are one or more alternative routes; in this case, the study moves on to stage 2.

\(^1\) This is not an absolute threshold value, but the result of a review of around twenty tunnels which had been subject to comparative risk analysis. The value is associated with the modelling methods used in the QRA model

\(^2\) The same TDG prohibition or authorization measures may be applied to successive tunnels on the same itinerary, if there is no opportunity to leave the route between tunnels. In this case, it may be that the intrinsic risk for each individual tunnel is below the threshold, but the sum of all of their IR values is above the threshold. It is the sum of IR values which needs to be taken into account.
4. Content of stage 2 (route comparison)

Stage two is divided into two steps. In one, the expected value (EV) criterion for the number of fatalities is used (see section 2.1 above). The other is only performed if the EV criterion does not produce conclusive results, in which case further associated criteria are applied to assist in the decision-making process.

4.1 Step 1: Comparison between Expected Values

a) Definition of alternative routes to be studied

The owner must first define the alternative routes to be studied, in conjunction with the consultancy. The choice should be limited to a maximum of three alternative routes, with preference being given to the closest routes. It may prove necessary to have different alternative routes depending on the start and end points for the TDG movements. The points will therefore need to be identified beforehand in the TDG traffic survey.

The study of alternative routes will only look at TDG traffic which is diverted onto the route if it is prohibited from taking the tunnel. No account should be taken of TDG traffic which would be using the alternative route in any case, whether this traffic is authorized to take the tunnel or not.

Appendix B gives a more detailed explanation of the methodology used to identify and support alternative routes, together with a concrete example of the process.

b) Collecting and using data for the QRA model

Appendix A indicates the data which the owner and the consultancy need to collect for each of the routes, and outlines the principles applicable to the use of this data by the consultancy. The consultancy then runs the QRA model for each route.

The results obtained should be treated with caution due to the assumptions and techniques used for modelling the factors processed by the software and the uncertainty regarding the data entered. The robustness of the results will need to be tested by conducting sensitivity analyses on the model input parameters. In step 1, the only results which are used are the ones which relate to expected values.
c) Does the EV criterion produce conclusive results?

The sensitivity analyses already performed by the designers of the model show that the following method is useful in determining whether the difference between the EV values for pairs of routes is significant or not:

✔ **The ratio of one EV to the other is greater than 10**: in this case, the difference between the EV values for the different routes can always be considered as significant, and so a decision can be taken without having to apply further criteria.

✔ **The ratio of one EV to the other is below 3**: here, the difference between the EV values for the different routes will always be considered as not significant and other criteria must be applied (see step 2 below).

✔ **The ratio of one EV to the other is below 10 and greater than 3**: the difference between the EV values for the different routes will only be considered to be significant if the sensitivity analysis produces situations which are deemed to be plausible which place the EV difference value above ten and does not produce any of these situations if it is below three.

The owner may also feel it useful to complete the comparison of the EV values by studying the consequences of measures designed to reduce TDG risks in the tunnels (see chapter 5) over and above those taken into account in the QRA calculation.

### 4.2 Step 2: Application of other criteria

As indicated above, other criteria are only applied if there is no significant difference between the EV values. The following list gives the main criteria (in no particular order):

✔ decider's "risk aversion" (a),

✔ TDG accidents not involving hazardous material (b),

✔ route vulnerability to a TDG accident from economic and environmental points of view (c),

✔ economic implications of the decision (d).

#### a) Risk aversion

If conclusive results are not obtained by comparing the expected values of the number of fatalities due to dangerous goods on each itinerary, the next step will be to determine whether, in the same way as public opinion, the decider may ascribe more importance to an event which causes ten times more fatalities even if it is ten times less probable; this is what is known as "risk aversion."
The most meaningful way to analyse aversion to risk is to consider the relative weight of the most serious events in the EV, using an appropriate graphical method (see appendix A). Appendix D contains a more detailed discussion of the concept of risk aversion and the various methods which can be used to account for it.

b) TDG accidents not involving hazardous material

When TDG traffic is prohibited from passing through a tunnel, it is effectively prohibited from an entire route. However, the prohibition has been applied due to the disasters which can occur inside a tunnel following an accident in which the hazardous material has been released (known as an "M" type accident). The route comparison made in the QRA software does not take account of the fact that the TDG movements also lead to a possible risks of road accidents on either of the routes during which the hazardous material carried is not released (known as a "C" type accident).

"C" type accidents have higher levels of probability, and if the QRA model included fatalities caused by these types of accidents, they would often have a preponderant impact in the EV values for the routes being compared (see appendix C). The fact that "C" type accidents are excluded from the EV calculation is already a form of recognition of risk aversion, as the analysis only considers the events which are potentially the most serious.

When EVs are compared, the comparison only takes account of "M" type accidents, and if the results are not conclusive, "C" type accidents can be used as an additional criterion. The consultancy should therefore assess the expected value, or annual number of fatalities produced by "C" type accidents for each route (i.e. circulation accidents where TDG is involved but no hazardous material is released).

c) Route vulnerability to a TDG accidents

The analysis has so far just considered consequences on humans. The inclusion of vulnerability means that information has to be gathered and compiled on the following points for each of the routes studied:

✔ presence of natural sites (in particular water courses) which may be affected by accidental pollution in the event of a hazardous material spillage;
✔ presence of structures (bridges and/or tunnels), buildings (historic monuments), industrial sites and so on which could suffer damage in the event of a TDG accident;
✔ problems which would arise if tunnels located on the different routes studied were subject to prolonged closure (extra mileage and time for taking detours, local economic impact, etc.);
✔ potential viability problems, in particular regarding snow and ice on different routes in winter and natural hazards such as flooding, avalanches, rock falls, landslides, forest fires, etc.;
✔ the proximity of the emergency services.

This list is not exhaustive.
d) Economic implications of the decision

Apart from the risks associated with accidents covered by all the previous criteria, the decision whether to prohibit or allow TDG movements also has economic implications both for the owner and for carriers and loaders. These impacts should be assessed if the results of the comparison of EV values are not conclusive, in particular:

- additional investment and tunnel operating costs arising from the authorization of TDG movements,
- the impact which the circulation of TDG vehicles will have on the environment on a particular route (apart from the impact of any accidents, covered by point c above),
- the inconvenience and additional costs borne by loaders and carriers as a result of the measures to prohibit TDG.

Comparing different routes by applying these criteria can assist in the decision-making process when EV analysis does not provide conclusive results by itself.
5. Measures to reduce risks associated with the transport of dangerous goods in tunnels.

Special requirements relating to new tunnels in which TDG movements are authorized, are contained in the "technical instruction" (instruction technique) attached in Appendix 2 of circular no. 2000-63 of 25 August 2000 relating to safety in tunnels on the French national road network.

Owners of all tunnels in which TDG movements are authorized must, in any case, determine whether risk reduction measures need to be put in place in the tunnel. Such measures may include the recommendations contained in the technical instruction relating to the infrastructure (the tunnel structure and installed equipment) and to the operation of the tunnel which have not yet been put into effect, and the prohibition of certain categories of dangerous goods, tunnel crossings in convoys or restricted hours. These measures are examined in the following paragraphs.

It should be noted that if the transport of dangerous goods is prohibited in the tunnel, checks must be performed to ensure compliance with this ban. Unless checks are carried out, a potentially highly dangerous situation could arise where some dangerous goods are transported without any technical or operational measures being taken to cope with any accident involving these movements.

5.1 Measures relating to the tunnel and operation of the tunnel

Section 7 of the technical instruction indicates action which can be taken with respect to the tunnel, installed equipment and the operation of the tunnel:

✔ adoption of tunnel geometry which prevents accidents generally, and prevents tanks from being holed in particular,
✔ improvement of drainage with sufficient cross slope and continuous slotted drainage channels to limit the surface area and presence time of a pool of flammable or toxic liquids,
✔ emergency exits located closer together to facilitate evacuation of users and access by the emergency services,
✔ ventilation system designed to handle fires with power values above 30 MW,
✔ upgrading of equipment for fire detection, communication with users, signalling, tunnel closure, fire-fighting, etc.,
✔ strengthening operating procedures.

1 The effectiveness of these measures is, to some extent, taken into account in the QRA model.
Application of the technical instruction is only mandatory for new tunnels and it leaves some room for discretion in connection with some of the measures indicated above, depending on the tunnel's sensitivity. The concept of tunnel sensitivity can also be used to analyse an existing tunnel.

In addition to the criteria given in section 7.1 of the technical instruction, the sensitivity of the tunnel can be gauged using the results of the TDG risk analysis, particularly the results of stage 1 which establish the tunnel's intrinsic risk. These results provide a means of assessing the portion of the risk associated with the different accident scenarios, as well as their relative importance.

### 5.2 Prohibition of certain categories of dangerous goods

If stage 2 indicates that the tunnel route is generally the safest although certain TDG movements present greater risks on the tunnel route, it may be useful to identify a prohibition grouping system which would ban movements selectively. The purpose of this prohibition is to reduce the overall risk for all routes.

On the other hand, if the tunnel route is generally less safe although certain TDG movements present greater risks on the alternative route, it may be useful to identify a prohibition grouping system which does not ban these movements.

Any desire to apply fine tuning TDG by TDG comes up against the fact that, as we saw earlier, apart from a total ban or unrestricted access, the regulations only allow for the prohibition of the two TDG groupings which correspond to sign B 18a (explosive or easily flammable substances) or to sign B 18b (products which may pollute water) (see 1.1).

Although B 18b has no great relevance for tunnels, it is recommended that an analysis is made of partial prohibition using B 18a. It is the owner's decision whether or not to perform this analysis depending on the context.

The change in the regulations which increases the TDG groupings to five may come into force in 2007, and the new road signs for these groupings will make it more practical to introduce partial prohibitions.

### 5.3 Transits in convoys with escorts

In large tunnels with toll-booth barriers or vehicle inspection facilities at each entrance, particularly tunnels with bi-directional way traffic, it is possible to arrange for all or some TDG movements to be accompanied through the tunnel. The vehicles concerned would be grouped together in convoys.

Despite the possibility of a multi-vehicle collision inside the tunnel, accompanied transit is undoubtedly an effective way of increasing safety. Safety is further enhanced if other types of traffic are prohibited while the TDG convoys are passing through the tunnel.
Quantification of this improvement needs a large number of further assumptions relating to areas where insufficient data is available, including accident and incident rates and associated disaster probabilities. This would almost certainly mean that the structure of the QRA software would have to be adapted, as it was designed for continuous traffic (see appendix E for a more detailed discussion).

The use of escorted transits needs a parking area and available staff to accompany the vehicles, and there are not many cases where both of these conditions are satisfied.

A vital point is safeguarding the waiting area for the TDG vehicles which will make up the convoy.

### 5.4 Time restrictions

The QRA model allows a distinction to be made between different periods, and therefore provides a means of seeing whether there is a change in which of the routes compared has the most risk during particular periods. This information could be used to apply and optimize time restrictions².

Optimization of this kind only produces significant effects if the difference in risk between the tunnel and the open air varies very considerably between peak and off-peak traffic times. This could be the case if high peak traffic corresponds to time when there are few local inhabitants along the route and vice versa.

Time restrictions are generally only of use if use of the tunnel is prohibited for all of the day and not just at peak periods (see appendix E for detailed discussion of this point). As with escorted transit movements, there needs to be a parking area available and this area must be kept secure.

**It is for the owner to decide whether an analysis of any time restrictions should be made using the QRA model.**

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² In order to gauge the effectiveness of measures of this kind, you have to know what the TDG vehicles are doing during the period they are prohibited from using the tunnel, i.e. whether they are taking alternative routes or adjusting their schedules so that they can travel through the tunnel. It is often difficult to tell how carriers will react in advance.
Appendixes

Appendix A  Introduction to QRA model

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- A.2. Use of the model within the framework of the approach adopted in France
- A.3. Use of models for comparing routes
- A.4. Results and their interpretation

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Appendix D  Risk aversion

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- D.3. Other aspects of risk aversion
- D.4. Re-examining policies regarding risk

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- E.2. Time restrictions
Appendix A

Introduction to QRA model

A.1 Joint OECD and PIARC research project

A.1.1. General background

One of the objectives of the joint research project conducted by the OECD and the PIARC was to provide a quantitative risk assessment (QRA) model which, as its name indicates, can provide a means of quantifying the risk associated with the transport of dangerous goods on a given route, including a tunnel or otherwise, taking account of two particular aspects, i.e.:

- the probability of the occurrence of certain events, and
- the severity of their consequences, in terms of:
  - loss of human life, with a possible distinction between the local population and road users;
  - non-fatal casualties, with a possible distinction between the local population and road users;
  - damage: destruction of buildings or structures and damage to the environment.

Regulations regarding the transit of vehicles carrying dangerous goods can take account of one or more criteria for the assessment or comparison of risks. Different countries have their own selection methods. The main ones are:

- assessment of risk on the basis of one or more risk thresholds previously specified in regulations: all sorts of criteria may be used, such as the mathematical "expected value", one or more threshold F/N curves, the maximum number of fatalities, and so on,
- comparison between one or more routes to allow selection of the route which is the most favourable in terms of risks on the basis of a number of specified criteria,
- a combination of the two types of criteria mentioned above.

The QRA model assesses several components of the risk so that one of these types of criteria can be applied. The QRA model can be used for many different purposes. The methodological framework in which it is used (and hence the criteria) need to be clearly identified so that the results provided by the model can be interpreted correctly.

The research project also allows the QRA model to be used in conjunction with a decision support model\(^1\) (DSM) which uses the results of the QRA model to suggest the most suitable regulations: the suggested solution is obtained from a calculation, in which different criteria can be weighted or correlated, and then from a comparison made using several choice methodologies specified in advance. DSMs are still at the experimental stage and are not used for practical applications.

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\(^1\) The Decision Support Model (DSM) is not used in France.
A.1.2. A model based on representative accident scenarios

The ADR lists several thousand different goods. In view of this, and in order to avoid using a method which is over-complex for the level of accuracy which can be achieved with this type of model, events were selected as being representative of the main risks associated with the goods transported.

The QRA model is therefore limited to a specific number of pairings of hazardous materials and packaging, combined with the types of accidents which can be produced by these pairings. As a result, the latest version (version 3.60) contains thirteen basic scenarios which are considered to represent events which produce a large number of casualties, even though this means that not every single accident is modelled in detail.

Table 1: List of scenarios included in version 3.60 of the QRA model

<table>
<thead>
<tr>
<th>Scenario n°</th>
<th>Description</th>
<th>Capacity</th>
<th>Size of breach (mm)</th>
<th>Mass flow rate (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HGV fire with no dangerous goods (20 MW)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>HGV fire with no dangerous goods (100 MW)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>BLEVE(^2) of 50 kg LPG cylinder</td>
<td>50 kg</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Motor spirit pool fire</td>
<td>28 tonnes</td>
<td>100</td>
<td>20.6</td>
</tr>
<tr>
<td>5</td>
<td>Motor spirit VCE(^3)</td>
<td>28 tonnes</td>
<td>100</td>
<td>20.6</td>
</tr>
<tr>
<td>6</td>
<td>Chlorine release(^4)</td>
<td>20 tonnes</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
<td>BLEVE of LPG in bulk</td>
<td>18 tonnes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>VCE of LPG</td>
<td>18 tonnes</td>
<td>50</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>Torch fire on LPG in bulk</td>
<td>18 tonnes</td>
<td>50</td>
<td>36</td>
</tr>
<tr>
<td>10</td>
<td>Release of ammonia</td>
<td>20 tonnes</td>
<td>50</td>
<td>36</td>
</tr>
<tr>
<td>11</td>
<td>Release of acrolein (in bulk)</td>
<td>25 tonnes</td>
<td>100</td>
<td>24.8</td>
</tr>
<tr>
<td>12</td>
<td>Release of acrolein (in cylinder)</td>
<td>100 litres</td>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td>13</td>
<td>BLEVE of non-flammable gas (CO2)</td>
<td>20 tonnes</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^2\) BLEVE: Boiling Liquid Expanding Vapour Explosion  
\(^3\) VCE: Vapour Cloud Explosion  
\(^4\) The chlorine release scenario should not be used as this material is not transported by road in bulk in France.
Two of these thirteen scenarios relate to fires which do not involve hazardous materials. These are given for guidance purposes. Version 3.60 also includes three optional scenarios relating to radioactive substances. These should only be used in exceptional circumstances, for example if a site requiring a large number of movements of radioactive material is located nearby.

The scenarios indicate the flow rate of releases of the hazardous material associated with each scenario. A number of specific circumstances (e.g. the weather) are applied, ending up with a great many situations to be taken into consideration.

<table>
<thead>
<tr>
<th>Scenario n°.</th>
<th>Description</th>
<th>Capacity</th>
<th>Size of breach (mm)</th>
<th>Mass flow rate (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Release of natural UF₆</td>
<td>9,471 kg</td>
<td>50</td>
<td>360</td>
</tr>
<tr>
<td>15</td>
<td>Release of enriched UF₆</td>
<td>1,743 kg</td>
<td>50</td>
<td>360</td>
</tr>
<tr>
<td>16</td>
<td>Radioactive source (gamma radiograph)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Although there is no particular problem in grouping together goods with characteristics which are close to each other, such as UN no. 1299 (turpentine) and UN no. 1300 (white spirit) into a limited number of representative scenarios, this approach is open to criticism if dangerous goods with significantly different characteristics are associated with a single representative scenario for the QRA model. For example, bulk transport of diesel is often associated with the bulk transport of motor spirit used in the QRA model.

The choice of representative scenarios must therefore be based on a comparison between the possible effects caused by the goods noted on the route and the effects caused by the goods used in the QRA model's representative scenarios. The scenario or scenarios finally adopted are the ones which are best suited. To some extent, the comparison between routes allows relative values to be used and this method makes up for the "approximations" applied in the exact risk assessment.

However, the objective is to get as close as possible to the actual risk, and modelling is bound to fall short of this aim for two main reasons: on the one hand, the TDG traffic taken into account does not necessarily correspond to the actual traffic because the analysis only takes account of normal traffic which can be diverted onto other routes, and on the other hand, the dangerous goods noted on the route are not always those associated with the representative scenarios used in the QRA model. Nevertheless, what is clear is that the assessed risk is generally under-estimated as in the case of the bulk diesel tank mentioned earlier.

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5 The first two scenarios in the QRA model relate to HGV fires which do not involve hazardous goods and should therefore obviously not be taken into account in the study of risks associated with TDG. At first sight, it may appear useful to associate the results of these scenarios with the results of the specific hazard investigations, but it should be stressed that the standard specific hazard investigation scenarios use different fire power values.
The important points to remember are:
✔ the quantitative risk assessment is based on a simplification which consists of using representative pairings of dangerous goods and accident scenarios; all of the dangerous goods identified for the route are associated with one or more of these representative pairings;
✔ the process of associating the goods which are normally recorded and one or more representative pairings requires a thorough knowledge of the properties of the goods and a thorough knowledge of the model;
✔ the risk assessed using the QRA model is closely linked to the method used. It is clearly not exactly equal to the actual risk, although it is assessed in a way which is as close as possible to the actual risk, and at least provides a basis for relevant comparisons to be made between routes.

A.2. Use of the model within the framework of the approach adopted in France

The approach adopted in France only takes account of the results of the model in terms of fatalities. It is divided into two stages, both of which use the QRA model; the results of the first stage determine whether it is useful to carry the risk assessment further and proceed with the second stage which compares different routes. The first stage is a simplified analysis aimed at making a rough assessment of the factors involved, whereas the second offers a full analysis which provides a means of actually comparing routes.

A.2.1 Use of the model in association with the calculation of intrinsic risk (IR)
(see section 3: Content of stage 1)

Modelling only uses the QRA model to a limited extent, and is only intended for the assessment of direct risks brought about by the presence of the tunnel.

It only takes account of a single route, and this route is formed by the tunnel itself. The start and end points of the route are therefore the two portals of the structure.

It is simpler to collect the input data, because:
✔ the area included in the study is limited to the surroundings of the tunnel (the local population is only taken into account in the vicinity of the portals),
✔ the traffic data (and in all probability, the accident statistics) do not change along this short route.

The IR calculation therefore only makes use of a very small part of the potential of the model and only needs data on the tunnel itself.

Refer to the guide on the methodology of intrinsic risk calculation available from the CETU for further details.
A.2.2. Use of the model in route comparison (see section 4: Content of stage 2)

In this case, modelling using the QRA model is more complex as the study takes account of a number of different routes including one or more tunnels.

The amount of input data to collect depends on the size and complexity of the area under study. Additional information needs to be gathered, on top of the data already established for calculating the IR value. Some of this data may be collected by the consultancy performing the route comparison.

The following section is concerned with use of the model for the second stage.

A.3. Use of models for comparing routes

The modelling process consists of the following five steps: Steps 1, 2 and 5 in particular require the involvement of the tunnel owner, or the tunnel operator or both.

✔ Step 1: Collection of the data required for modelling;
✔ Step 2 : Selection of parameters (choice of scenarios, division of routes into homogenous sections and choice of time periods to be considered);
✔ Step 3 : Calculation;
✔ Step 4 : Sensitivity study;
✔ Step 5 : Interpretation of results and conclusion.

A.3.1. Step 1: Collection of the data required for modelling

Quantitative assessment of the risks associated with the transport of dangerous goods is chiefly based on gathering specific items of data required for using the QRA model:

✔ for the route studied: definition of the geometry of the route for each direction of travel in Lambert coordinates established on the basis of the horizontal alignment and longitudinal section of the route,

✔ for the tunnels\(^6\): length, slope, crossfall, section, hydraulic diameter, location of emergency exits, characteristics of liquid effluent collection system, ventilation and smoke-evacuation system performance characteristics, level of surveillance, etc.

\(^6\) At this stage, it is important to make it clear that as far as the model is concerned, a tube corresponds to a section in the model and that a tunnel cannot and must not be sub-divided into several sections as this may give incorrect results. Chapter 9 of the QRA software User Guide must always be consulted before entering a description of a tunnel in the model.
• for traffic:
  - heavy goods vehicles, light vehicles and coaches: volume of traffic, including seasonal or day-to-day variations, etc.,
  - for TDG movements: type, volume including seasonal or day-to-day variations, start and end points, etc.; TDG data is only included for traffic which may be diverted onto the other route or routes studied,

✓ for traffic conditions: maximum speed, speeds practised by different categories of users, risks of congestion, accident statistics, involvement of light vehicles, etc.,

✓ for surveillance and operation of the route: description of means of surveillance and traffic management equipment, assessment of time needed to close route, etc.,

✓ for weather conditions: wind rose,

✓ for population: description of density of population in 1,000 metre strip around the routes studied; (this relates to the resident population and, as applicable, people at work, visitors to places open to the public and so on).

The more accurate and the more compete the data gathered, the more representative the quantitative risk assessment will be.

Some of this information can be obtained straight from the owner or the operator, while other data may need to be collected elsewhere - with the complexity of the process depending on the local environment. Some data collection operations can of course be outsourced.

Some essential data may be difficult to obtain to the level of detail required, as not enough relevant information is available, for example when accident statistics cover too short a period or are not yet available for tunnels which are at the design stage. In this case, the model allows use of default values which at least allow the process to continue. The study of sensitivity to the different parameters will then make it possible to assess how sensitive and how representative the result is.

On the other hand, data defining the route, including the tunnel, and data on traffic must always be obtained before the calculation can be performed.

As a final point, it should be made clear that the level of detail of the data collected may be significantly different from one route to another; for example, the accident data for a route which is on a motorway will be quite different to the data for a route which is on the secondary road network and carries little traffic. In this case, it is important to try to apply as consistent a level of description as possible for the routes to avoid introducing any bias into the comparison. In any event, if the level of detail of description data applied to a parameter which plays a key part in the results produced is not consistent, the sensitivity study will need to be particularly detailed on the point concerned.

7 Up to three time periods can be specified. It is recommended that the maximum possible number of time periods is used and that the same number of time periods is used for each route studied. The emphasis will obviously be on the most sensitive day-to-day or seasonal variations which match the variations in populations noted in the neighbourhood of the route.
Special considerations on collection of TDG traffic data

TDG traffic can be identified on the road by the orange plates placed at the front and the rear of the vehicle. These plates normally contain two numbers. When displayed, these numbers are as shown below, i.e.:

- the Hazard Identification (HI) number (2 or 3-digit number),
- the UN number (4-digit number).

The HI number and the UN number must be noted, from the front or the rear of the tank body.

If the plate at the front or rear of the vehicle does not contain any numbers, this means:

- either the vehicle has several tanks (or several compartments within the same tank body), in which case a number of plates bearing HI and UN numbers are attached on the side of the HGV. This situation generally only arises on a small minority of TDG movements. In these cases, it is important to establish whether all of the dangerous materials have the same HI number (e.g. 33) or whether they have different HI numbers (e.g. 30 and 33). This information helps decide on the representative scenarios to be adopted;

- or the vehicle is a tarpaulin-covered lorry. In this case, it is often difficult to identify the goods carried from the outside. These goods are generally in small containers (paint, flammable liquids in packaging, etc.). In practice, these movements only account for a small portion of the traffic and, except in special cases, they can be omitted from the initial approximation used to determine the scenarios to be used;

- or the material is transported in cylinders. In this case, hazard labels must be noted to associate the transport concerned with either scenario 3 (flammable liquefied gas cylinder) or 12 (toxic substance in container).
A.3.2 - Step 2: Selection of parameters

A.3.2.1. Step 2.1: Choice of scenarios

The work performed at this stage generally consists of associating the hazardous goods normally noted on the route with the most representative QRA model scenarios.

In some cases, the HI number itself is enough to select the representative scenario or scenarios. In other cases, particularly with dangerous goods where the primary or secondary hazard relates to toxicity, the corresponding UN numbers also need to be taken into account.

The reader may obtain a chart from the CETU on request showing the correspondence between HI numbers and QRA model scenarios. This chart is used when making the initial approach to the calculation of the tunnel's intrinsic risk. It is obviously not meant to take the place of the expert knowledge required regarding the individual properties of the goods identified (i.e. the material and the container in which it is transported). The chart is merely intended to serve as a guide which allows a consistent approach to establishing how representative the scenarios included in the model actually are.

The purpose of this analysis is to determine the composition of the TDG traffic to be handled by the model and to define the representative scenarios associated with this traffic. It is therefore important to ensure that the TDG traffic data is collected accurately (see table 2).

Table 2: Example of TDG traffic described on the basis of HI numbers

<table>
<thead>
<tr>
<th>HI number</th>
<th>% of TDG traffic</th>
<th>DG: observed (recorded) or projected (from survey)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>6%</td>
<td>Nitrogen or refrigerated liquefied CO2</td>
</tr>
<tr>
<td>23</td>
<td>4%</td>
<td>Natural gas, compressed hydrocarbon gases, LPG</td>
</tr>
<tr>
<td>30</td>
<td>19%</td>
<td>Diesel, liquid tar</td>
</tr>
<tr>
<td>33</td>
<td>40%</td>
<td>Gasoline, ethanol, isopropyl acetate</td>
</tr>
<tr>
<td>50</td>
<td>7%</td>
<td>Ammonium perchlorate and persulphate</td>
</tr>
<tr>
<td>60</td>
<td>3%</td>
<td>Toxic organic liquids, solid pesticides.</td>
</tr>
<tr>
<td>80</td>
<td>20%</td>
<td>Phosphoric acid</td>
</tr>
<tr>
<td>90</td>
<td>1%</td>
<td>Miscellaneous dangerous substances</td>
</tr>
</tbody>
</table>

A.3.2.2. Step 2.2: Choice of time periods

A maximum of three time periods can be specified on the basis of the traffic and population data (times of day or times of the year). When a period is specified, it can be used to take account of variations in traffic, accident statistics, adjacent populations and, in some cases, the geometry of the route (for example when a route is not used in winter).
A.3.2.3 Step 2.3: Dividing the routes into homogenous sections

The purpose of this step is to cut the route or routes up into sections which are homogenous in terms of traffic, accident statistics and geometry for each of the time periods specified previously.

The consultant generally carries out this step before the calculation is made.

A.3.3. - Step 3: Calculation

The calculation is performed by the consultancy. It is important that the calculation is performed by an experienced professional who knows how to identify sensitive or difficult points in the case under analysis.

A.3.4. - Step 4: Testing and sensitivity

In view of the uncertainty associated with the input data, it is necessary to verify the impact which the most important parameters have on the result of the calculation. This test is used to assess how representative and how robust the results in fact are.

The sensitivity of a result is assessed by looking at how the expected value of the annual number of casualties associated with the risk changes when a single item of input data is altered, with all other factors remaining unchanged. The extent of variation in the altered input data depends on the uncertainty range associated with the item of data concerned. Some sensitivity calculations therefore need to made for all of the routes studied.

The robustness of the analysis provides a general indication that the main conclusions drawn from the model will not be undermined if the input parameters vary within a particular uncertainty range.

A.3.5. - Step 5: Interpretation of results and conclusion

The interpretation of the results and the conclusion of the assessment depend on the type of analysis performed, i.e. IR calculation or comparative route analysis. It is an important stage, as it provides an opportunity to review what has done and highlight the main lessons to be drawn from the work performed. It is extremely important to stand back from the figures obtained from the calculations and from the approximations and uncertainties which are inherent in this method, and go back to what really is involved.

The following section should make this clear to the reader.

A.4. Results and their interpretation

The model provides very full results. The most succinct data provided by the results is the expected value, denoted "EV", which corresponds to the statistically forecast number of fatalities each year. The EV can be calculated for each accident scenario, for a set of scenarios chosen by the operator, for all scenarios related to the same type of dangerous goods and, most importantly, for all scenarios for all dangerous goods taken into account in the modelling operation.
In addition to expected value, the QRA model also provides results which can be used in a more detailed analysis. It plots frequency against severity in F/N curves which give the frequency (F) of scenarios causing N or more fatalities for different values of N, in logarithmic coordinates. These graphs provide an indication of the proportion of accidents causing multiple fatalities on each route, and if necessary for each type of dangerous goods.

Figure 1: Example for one route: three F/N curves relating to a TDG type and one F/N curve for all scenarios.

These types of curve reveal the contribution that each type of dangerous goods (and even particular types of packaging) make to the overall risk on the route. The above example shows:

- Most of the risk on the route passing through the tunnel is associated with LPG, whereas most of the dangerous goods transported are flammable liquids;
- Flammable liquids are the most important factor in accidents causing a single fatality;
- LPG is much the most important factor in accidents causing more than 20 fatalities;
- In terms of EV, LPG causes twice as many fatalities as flammable liquids.

The first elements used in the comparison between routes are the F/N curves for each route showing the sum of probabilities for all scenarios. Curves for all scenarios for different routes can be superimposed on the same graph.

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8 F/N curves use logarithmic coordinates for practical reasons, as there are very wide ranges of values involved. With linear coordinates, the area beneath the curve would equal the expected value.
The two curves intersect in the example given in figure 2:

- the route through the tunnel has the highest frequency values for risks causing the greatest number of fatalities (more than 10),
- both routes have very close frequency values for risks leading a smaller number of fatalities (less than ten or so) and the curves cross over each other.

The expected value for the tunnel route is twice the EV for the alternative route (8.10^{-3} fatalities on the tunnel route and 4.10^{-3} on the alternative route). However, this variation is not sufficient to indicate that there is a significant difference in risk between the routes being compared, in view of the uncertainty associated with the input data and the uncertainty inherent in the model.

Different view modes can be applied to the graphs as part of the study, in particular to include risk aversion (see below).

The results of the model can also be used to plot cumulative curves for each tunnel showing the contribution to the overall risk (i.e. the EV for the route) of the events modelled on the basis of their severity. These curves can then be compared against each other. For example, the following curve shows that on the route through the tunnel, 50% of the expected value comes from scenarios causing over 60 fatalities, while 50% of the EV on the alternative route is associated with scenarios with less than five fatalities. Scenarios with more than 40 fatalities on the alternative route only account for 5% of the EV.
Figure 3: Curves showing the percentage contribution to EV made by events according to severity - for each route

The information shown in these view modes needs to be interpreted with care. For example, in the above illustration, the graph compares proportions of the contribution to an EV brought to a single base level of 100. In fact, the EVs for the two routes are not the same, even though they are close in terms of relative size (as shown on figure 2). This method of representing the data should therefore only be used in cases where the expected values for the routes are close.

A large number of curves can be generated in this way. The final report should only contain curves which provide information which is useful to a better understanding of the study.
Appendix B

Choice of alternative routes

The question of the choice and comparison of alternative routes is raised in the second stage of the TDG risk analysis.

In order to be relevant, the alternative routes will obviously have to possess the road characteristics necessary for allowing vehicles carrying dangerous goods to take the route, in particular semi-trailers. These routes must also not be subject to any measures which prohibit these types of movements or vehicles (e.g. through town centres, other tunnels, structures with reduced clearance height and so on)\(^1\).

Sometimes, the routes to be compared choose themselves. In particular, when a planned tunnel is on a new route, the alternative route considered will naturally enough be the route taken by TDG movements in the past. Other cases may be more complicated (see example given below). The best method is to attempt to determine the choices which the TDG carriers would make themselves and in this way establish the probable diversion taken by traffic if there is a total or partial ban on the route passing through the tunnel\(^2\).

The question can also be viewed according to the type of dangerous goods involved and where these movements start and end. For example, the lengths of suitable alternative routes for arterial routes or for local traffic movements may be very different, with the respective points at either end of the route being very far apart.

**In order to be in a position to make a satisfactory comparison, it is important to ensure that the data on the TDG traffic includes sufficient information on the composition of this traffic and on where the vehicles involved start and end their journeys.**

The alternative route for long-distance transport and arterials can sometimes start a considerable distance before the tunnel, and so diverting TDG traffic can affect a very large area. It is important to beware of the fact that the longer the routes being compared, the smaller the contribution made to the route's EV by the tunnel as such, and the route comparison may take on issues which are not specifically related to the tunnel\(^3\).

The recommended practice when looking for alternative routes is to start with the routes which are closest to the tunnel and only to widen the investigation if necessary. In any event, it is not generally useful to select and analyse more than three alternatives to the tunnel route.

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\(^1\) the route comparison could take account of routes like these which appear to unusable, if a general review is to be conducted.

\(^2\) Routes which would be unlikely to take much diverted traffic can be excluded straight away. The comparative risk analysis is only interested in diverted traffic. This means that the comparative analysis would not include TDG movements which would not go through the tunnel anyway, like traffic on local routes for example, even if these movements are a component in the overall traffic on the alternative route being examined.

\(^3\) EVs are generally high with very long routes, but there is not a great deal of difference and the values are more or less proportional to the lengths of distance travelled in the open air.
Example of choice of alternative routes: The Dullin and l’Epine tunnels on the A43 motorway

The search for possible routes to avoid the Dullin and l’Epine tunnels on the reference route (the A43 motorway between Lyon and Chambéry) started off with an attempt to find a local solution. Two alternative routes stood out: both involved a detour of around 30 kilometres on trunk roads.

*Alternative route 1* (shown in dark green) has to be eliminated straight away as it includes the "Tunnel du Chat" tunnel which prohibits TDG movements, and there is no question of this ban being lifted.

*Alternative route 2* (in blue) deserves to be looked at more closely, despite the presence of the "Tunnel des Echelles" tunnel and a number of sections in built-up areas where the road is narrow and winding in places, but not impassable for semi-trailers.
Other alternative routes suggest themselves if the scope is widened. These routes have the advantage of being entirely on motorways, and this alone would encourage some carriers to take them even though they involve longer detours (from over 100 to 200 km depending on the origin and destination of the TDG movement).

Alternative route 3 (in blue) passes on the A 48 and A 41 motorways via Grenoble and represents a credible alternative, despite the density of traffic on Grenoble's southern ring road section.

In contrast, alternative route 4 using the A 42, A 40 and A 41 motorways via Geneva and Annecy is out of the running, not just because of the length of the detour involved, but also because of the large number of underground structures it contains (the Chamoise, St Germain, Châtillon and Vuache tunnels).

In this example, the CRA ended up comparing the reference route against two alternative routes, a local one using trunk roads (no. 2) and a regional one using motorways (no. 3).
Comparison between "C" and "M" type risks

This guide indicates that comparisons between routes only consider "M" type accidents, which are accidents where the dangerous goods transported are actually released or where the number of fatalities is a direct consequence of the dangerous goods.

"C" type accidents do not involve the release of the hazardous material and are similar to standard HGV accidents. The inclusion of these accidents would mask the specific effects of the risk associated with the hazardous material when the expected value (EV) is determined.

However, if the alternative routes seem highly comparable in terms of the risk associated with the hazardous material, it may be useful to conduct a further analysis on "C" type accidents to assist in the final decision.

Accident studies for the 1987-1997 period show that "M" type casualty accidents represent around 40% of casualty accidents involving TDG traffic. The severity of these accidents in terms of the number of injuries and fatalities is very close to the severity of the "C" type accidents. This could be explained by the fact that most of the accidents which involved the spillage of hazardous material during the period in question did not develop into major incidents.

There is a need to examine this aspect further, and take account of the risk of major accidents, even though there is a very low probability that they will occur. To give a general idea of what this means in the QRA model, the conditional probability that a material-type accident involving a vehicle transporting dangerous goods will degenerate into one of the serious incident scenarios included in the model is an average of 2 in 1000 in the open air and 5 in 1000 in a tunnel.

The QRA model can be used to compare the risks associated with "C" and "M" type incidents. Calculations performed on several tunnels show that the EV for "C" type accidents is between two and thirty times greater than the EV for "M" type accidents. The average is nine times greater.
Appendix D

Risk aversion

Risk aversion is a factor used to weight results according to the type of population concerned by the risk (road users, residents along the route, the local population, etc.), or according to the number of fatalities which could be caused simultaneously by the accident, in order to incorporate how society perceives the consequences and conditions of the accident.

D.1.- Different levels of risk aversion

Risk aversion can be characterized at two levels:

- The first level relates to the type of population exposed to this risk. The QRA software allows a distinction to be made between road users and people resident along the route. The analysis can also be extended by taking the causes or the place of the accident into account.

- The second level relates to the severity of accidents for a given population and a given accident cause. The EV calculation is adjusted to give greater weight to accidents which could cause a large number of fatalities.

The expression is:

\[ EV = \sum_{i=1}^{N} f(N_i) \cdot N_i^a \]

where \( N_i \) is the number of fatalities caused by accident "i", \( f(N_i) \) is the probability of its occurrence and "a" is a real number greater than 1 (called the "aversion factor"). The aversion factor determines the weighting associated with severity.

In the Netherlands, the value for the aversion factor has been set at 2, which means that the weight applied in the EV calculation for an accident causing 100 fatalities is 100 times higher than for an accident causing 10 fatalities. Other countries, including the U.K. have deliberately decided not to use any aversion factor (\( a = 1 \)).

The choice of whether to use an aversion factor and what the value assigned to the factor should be are not based on "technical" data but on "societal" considerations which more broadly include the concept of society's perception and acceptance of the risk.

It would be a mistake to think that the use of an aversion factor solves the problem entirely. In the QRA model, the number of casualties resulting from the envisaged event can range from one to several hundred, depending on the type of event. It is quite reasonable to wonder whether the reaction of the public is not always the same beyond a certain point, i.e. the risk is considered unacceptable. With the use of an aversion factor, accidents with fifty fatalities have much more
impact than five accidents with ten fatalities, although this does not necessarily reflect how public opinion can be expected to react if such disasters occur more than once.

D.2. Choice of "M" type accidents or implicit aversion:

CRA approaches only take account of the casualties of "M" type accidents. This is an implicit weighting mechanism which corresponds to level 2 aversion, since the scope of the types of TDG accidents considered excludes "C" type accidents which are the most normal from the point of view of accident statistics and are characterized by high frequency and a more limited number of casualties.

D.3. Other aspects of risk aversion:

Since the aim is to weight the societal impact of an accident in terms of its consequences, other aspects besides just the number of fatalities can also be considered, even though it is obviously always going to be difficult to weigh human lives against environmental or material risks.

One approach would be to "cost" each of the potential impacts so that they can later be added up to determine an overall risk value, using methods close to the methodology employed for assessing the socio-economic impact of projects.

It is no easy matter to cover the different factors involved, or to apply the relevant selection criteria. An approach which applies one criterion after another may lead to different routes being recommended depending on the criterion concerned. Decisions have to be based on a form of multi-criteria analysis to be established on a case-by-case basis.

D.4. Re-examining policies regarding risk

Recent tunnel disasters (even though dangerous goods traffic was not involved) and the accident at the AZF fertilizer plant (which did involve hazardous material) have demonstrated that these incidents are followed by major changes in regulations and renewed calls to provide ever greater levels of safety. Even though, from an objective standpoint, the number of fatalities remains relatively low when compared with the public health and road safety problems as a whole, the impact of these disasters was sufficiently traumatic to force a profound change in risk-management policies both in France and throughout Europe.

The question is therefore whether it is reasonable to consider that, on paper, ten times ten deaths are more acceptable than one times a hundred, if, as soon as an event resulting in ten fatalities leads to a review of risk-management policies and helps prevent the occurrence of the other nine events? This example shows how complex the subject really is.
Appendix E

Effectiveness and application of measures designed to reduce TDG risks

This appendix looks at just two of the different measures which can be taken to reduce the risks associated with the transport of dangerous goods in tunnels: transit in convoys and time restrictions.

E.1. Transit in convoys under escort

E.1.1. Different types of escorted convoys and advantages of the concept

There are several ways of organising convoys of vehicles transporting dangerous goods. There are three main methods:

- Convoy travelling on a route which is totally closed to other vehicles,
- Convoy travelling on a route using a single lane in each direction which is left fully or partly open to other traffic,
- Convoy travelling on a route with more than one lane in each direction which is left fully or partly open to other traffic.

At first sight, the third method appears to have very limited usefulness. It is only meaningful to arrange convoys if this helps decrease the probability of accidents occurring and reduce their potential severity. Any advantages which this might bring disappear rapidly if other vehicles are allowed to move about freely around the convoy. This method will not be considered in the remainder of this appendix.

In all of these cases, the convoys are made up of vehicles transporting dangerous goods plus escort vehicles. Traffic rules are applied to convoys concerning points such as:

- the maximum number of TDG vehicles allowed in the convoy,
- the maximum permitted speed,
- distance between moving vehicles,
- distance between stationary vehicles (if applicable).

One of the most-frequently raised objections to the use of convoys relates to how an accident can spread and the risks of domino effects 1. This disadvantage can be partially reduced by strict compliance with the specified distances between vehicles and is offset by the distinct benefits mentioned below.

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1 The domino effect is when an accident spreads from vehicle to vehicle or from vehicle to tunnel installations.
E.1.2. Reducing the incidence of TDG accident scenarios

Vehicles in a convoy all observe a moderate maximum speed and maintain a specified distance between each vehicle. As the convoy is travelling on a single lane, other vehicles cannot overtake the dangerous goods being transported. This clearly brings a very considerable reduction in the probability of an accident leading to a serious scenario.

Some of the incidents involving hazardous materials are caused by loss of containment or a spontaneous fire rather than a traffic accident. Transit in convoys is even a favourable factor in relation to causes which are not related to traffic. Two things generally occur when vehicles carrying dangerous goods are placed in a convoy:

- the TDG vehicles halt in a designated area while waiting to be formed into a convoy,
- an escort accompanies the convoy as it passes through the tunnel.

These factors help to allow engines to cool down before the vehicles enter the tunnel and promote greater concentration during the transit. In some cases, the vehicles can be given visual inspections before the convoys start.

E.1.3. Reducing the severity of scenarios

If the route is totally or partially closed, fewer road users are likely to be located close to any accident which may occur. On top of this, the provision of an escort means that incidents on one or more TDG vehicles in the convoy can be detected more quickly, and tackled rapidly. The operating centre can be alerted immediately and the escort can reduce the time taken to raise the alarm if an incident occurs. If it takes less time to report the incident, both preventive and protective measures can be taken more quickly.

E.1.4. Incorporation of escorted convoys in the QRA model

Incidence

There are two possible ways of incorporating convoy movements in the QRA model:

- reduction in accident rates - after the causes of the accident have been analysed, it is possible to determine which are still relevant to the transit convoy and which are not.
- changing the "conditional probabilities" of having a particular scenario following an accident - however this assumes that sufficiently detailed statistical data is available.
The analysis which follows is an example of the application of the assessment of the reduction in the incidence of spontaneous accidents. The table shows the distribution of groups of accidents recorded in tunnels, and is based on the CETU's 1998 report on research into breakdowns, accidents and fires in French road tunnels ("Pannes, accidents et incendies dans les tunnels routiers français").

The first hypothesis is that the distribution of breakdowns, accidents and incidents for vehicles transporting dangerous goods and for other HGVs is similar.

It is then possible to assess how important the organisation of convoys is for safety. Allowing waiting lorries to cool down, performing visual inspections of TDG vehicles and surveillance while the convoy is being escorted all help to avoid the ignition of spontaneous fires, spillages and incidents due to poorly-secured loads. On the other hand, it would seem that there is no way to prevent vehicles from having punctures, running out of fuel or suffering brake or battery problems.

For the other types of incidents noted (turbo failures, engine trouble, transmission problems, electrical problems and other), there is reason to suppose that these could be cut down by 50% due to the cooling of mechanical parts in the waiting area. If we take the distribution of the groups of incident types shown in figure 1, and apply the reduction factor for convoy transit to each group, we find that somewhere in the region of 30% of the incidents can be avoided by forming escorted convoys.
Severity

The current version of the QRA model does not allow for inclusion of the reduction in severity brought about by the formation of convoys. Traffic is always defined as being continuous, and this is not the case when convoys are used. One of the possible ways of improving modelling is to define time periods which correspond to convoy periods. This method is still under development and cannot be employed without a very thorough knowledge of how the QRA software works.

E.2. Time restrictions

The QRA model allows for different time periods to be taken into account. This approach is only useful if the input data actually shows marked variations over time, i.e. at different times of the day, different times of the week, different times of the year and so on. These variations can relate to traffic (movements of TDG and/or other vehicles) or to the environment (changes in number of people close to the tunnel).

The model provides a means of calculating the risk associated with each of the periods specified in the form of F/N curves or expected values, and can then give the cumulative total for these risks. Even if the tunnel route presents a lower level of overall risk than the alternative routes, it may have a higher risk during a particular period. Suitably tailored time restrictions on TDG movements through the tunnel could reduce the overall level of risk.

The following situation provides an interesting example of a comparison between a tunnel route and an alternative route. Traffic is broken down into three periods to reflect significant variations in traffic and populations during the course of the day. It is assumed that the distribution of traffic in the time periods is not affected by the fact that one of the routes is used.

Table 1:
Example of results of route comparison applying time periods

<table>
<thead>
<tr>
<th>Expected value (EV)</th>
<th>Slack period</th>
<th>Normal period</th>
<th>Peak period</th>
<th>All periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel route</td>
<td>0.1.10⁻³</td>
<td>0.4.10⁻³</td>
<td>1.5.10⁻³</td>
<td>2.10⁻³</td>
</tr>
<tr>
<td>Alternative open air route</td>
<td>7.10⁻³</td>
<td>2.10⁻³</td>
<td>1.10⁻³</td>
<td>10.10⁻³</td>
</tr>
</tbody>
</table>

Possible explanations for this patterns could be:

- There is little road traffic during the slack period but there are plenty of people active along the alternative route (at night for example),
There is a high volume of traffic on the tunnel route during the peak period and not many people active along the route (periods corresponding to travel from home to work).

We can also make the assumption that road users make up the largest proportion of casualties on the tunnel route, and that most of the casualties on the open air route are among the local population, in view of traffic levels and population densities on the two routes. In this type of situation, the period with the highest risk on the tunnel route is the peak traffic period, while for the alternative open air route it is the slack period when there are plenty of people along the route. This could provide grounds for considering prohibiting TDG movement in the tunnel during peak periods only. However, although the figures in the above example give food for thought, the EVs do not differ by sufficient amount to provide full justification for a time restriction.

To conclude, the QRA model is capable of taking time restrictions into account. However, these measures only make sense in situations where there are actually large variations in traffic volumes, or population densities or both.
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At the request of the CESTR, the CETU set up a working party to put together a guide intended for all persons to whom road tunnel safety documentation applies.

The working party was made up of representatives from the CETU, the land transport department's dangerous goods transport unit (DTT-MTMD), the national industrial environment and hazards institute (INERIS), consultants, owners and operators, some members also belonging to the CESTR. The scientific management centre of the École des Mines in Paris (CGS-ENSMP) provided methodological and operational assistance to the working party.

_A list of those attending the working party meetings is given below._

_Michel Vistorky (Area), Pierre Kohler (Bonnard et Gardel SA), Yves Trottet (Bonnard et Gardel S.A.), Éric Cesmat (CSTB), Pascal Beria (DDE 13), Marilou Marti (DDE 13), Philip Berger (Docalogic Inflow), Romain Cailleton (DTT-MTMD), Daniel Fixari (ENSMP-CGS), Philippe Cassini (Ineris), Raphaël Defert (Ineris), Emmanuel Plot (Ineris), Emmanuel Ruffin (Ineris), Johann Lecointre (Ligeron SA), Philippe Pons (Ligeron SA), Éric Boisguerin (Scetauroute), Anne - Sophie Graipin (Scetauroute), Michel Legrand (Scetauroute), Pierre Merand (Scetauroute), Raymond Vaillant (Setec TPI), Pierre Carlotti (Cetu), M. Deffayet (Cetu), François Demouge (Cetu), Nelson Gonçalves (Cetu), Didier Lacroix (Cetu), Claude Moret (Cetu), Michel Pérard (Cetu), Philippe Sardin (Cetu), Marc Tesson (Cetu)._
The decision whether to allow vehicles transporting dangerous goods to enter tunnels is based on risk analyses which are conducted in two stages.

The first stage consists of assessing the intrinsic risk induced by the circulation of vehicles transporting dangerous goods in the tunnel.

If this risk is above a certain threshold, the analysis moves on to a second phase where risks are compared between the route on which the tunnel is located and one or more alternative routes.

This booklet describes each of these two stages in turn in a simple and practical manner. Interested readers will find additional information on the method adopted and the reasons for using it in the appendices.